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Estuarine Research Report 34

Ecology of the Avon-Heathcote Estuary: Comparative Salt Marsh Survey 2006-2007

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Cover photograph: View towards the north across the Avon-Heathcote Estuary (Kimberly Jupp)

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Executive Summary

1. As cities cope with increasing populations, salt marshes around the world are on the decline due to negative effects of high levels of development, draining and reclamation. Due to high levels of disturbance in estuaries, monitoring is essential to ensure that salt marshes are preserved for future generations through sustainable management.

2. During the summer of 2006/07, salt marsh vegetation surveys were undertaken in the Avon-Heathcote Estuary, Christchurch, New Zealand using the same study areas as in McCombs and Partridge (1992). Global Positioning Systems (GPS) were used to capture each of 14 study sites to enable a high degree of accuracy. GPS were also used to create a detailed map of the margins of the estuary and to determine the locations of salt marsh vegetation.

3. The main aims of the study were to evaluate the current area of salt marsh vegetation in the Avon-Heathcote Estuary, to describe the community types and assess if these have changed since 1991/92.

4. A total of 12 vegetation types were found in 2006/07 compared with 15 in 1991/92. Oioi Rushland (Type 1) with 340 sites and Sea Rush Rushland (Type 2) with 205 sites were the dominant community types in the Avon-Heathcote Estuary.

5. Salt marsh vegetation in the Avon-Heathcote Estuary has changed since 1991/92. Salt tolerant plants, such as New Zealand Musk (*Mimulus repens*) and Suaeda (*Suaeda novae-zelandiae*) have been replaced by less tolerant plants, such as sea rush (*Juncus krausii*) and Oioi (*Apodasmia similis*). This is most likely due to increased sedimentation of finer sediments from developments around areas such as the Heathcote River. Of the original 495 sites, 27 had no vegetation in 2006/07.

6. The salt marsh near the Avon River had the most stable vegetation, dominated by Oioi Rushland (Type 1) and Sea Rush Rushland (Type 2). They shared an index of stability of 0.83, that is 83% of the survey sites remained the same from 1991/92 to 2006/07. In contrast, Sandy Point and the study area above Ferrymead were the most unstable areas and had changed the most.

7. The GPS map confirmed a high proportion of built structures compared to natural substrates around the margins of Avon-Heathcote Estuary. The total area of salt marsh in the Avon-Heathcote Estuary, determined from GPS measurements, was 372163 m^2 (0.37 km^2). The largest area contiguous of salt marsh was on the Avon River (Study area 1), with the smallest area at Sandy Point (Study area 8).

8. To encourage protection of the salt marsh vegetation in the Avon-Heathcote Estuary the survey should be completed again within 8 to 10 years. The present study forms a baseline for future comparative research which focuses on changes to the estuary and its salt marshes, this may be particularly important after 2008 with removal of the treated wastewater from the estuary.

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1.0 Introduction

Salt marshes around the world are under threat due to increase human activity placing pressure on them. Increased development, draining and reclamation are all factors which have caused salt marsh vegetation to decline. Salt marsh vegetation around the world is dominated by herbs and grasses (Woodroffe 2003). Environmental factors such as temperature affect where salt marsh species grow around the world. For example, in New Zealand, the southern most location for mangroves is Kawhia. It is extremely important to monitor the ecological characteristics of estuaries and their salt marshes that are in urban environments. This is due to their complex, dynamic and sensitive nature. The Avon-Heathcote Estuary is an important natural feature of the Canterbury region (Christchurch City Council. 2001). Located in eastern Christchurch (Figure 1.1), it contains one of the largest areas of salt water creek in the province (Rodrigo 1985). Salt marshes are intertidal systems influenced both by land, the saline waters and are subject to periodic inundation by the tide.

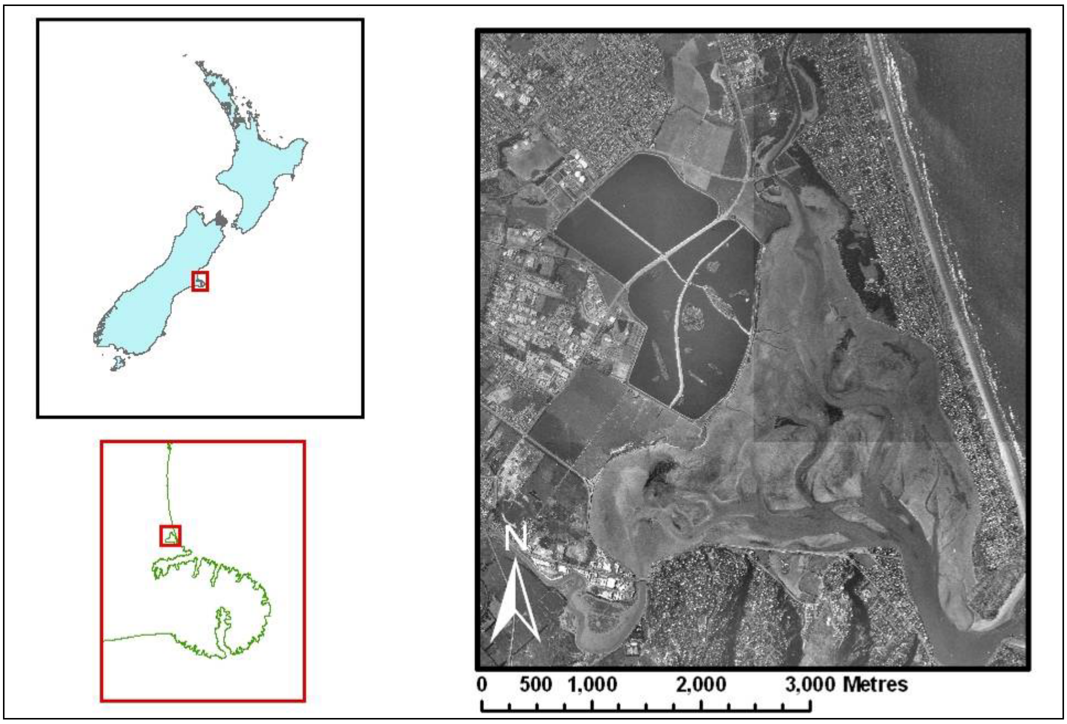

Figure 1.1 Location of the Avon-Heathcote Estuary study area in Canterbury, New Zealand

The Avon-Heathcote Estuary's salt marshes are under threat due to the highly contestable nature of the waterbody and its catchment. The estuary is a not only home to many native New Zealand species but is also a popular recreational and tourist area, with fishing, wind surfing and yachting all vying to use the area (Christchurch City Council 2006). Urban development is another important factor placing pressure on the salt marshes. The 21st century has seen a significant increase in the number of people living near the coast. Two thirds of the world's population, 3.6 billion people, live within 150 km of a coastline. This value is predicted to increase by 75% within the next three decades. This trend has had major effects on coastal ecosystems (Hinrichson 1994). Urban development has brought significant runoff of fine sediment from construction sites as well as pesticides and fertilisers from gardens. There is also evidence of residents clearing salt marsh around their dwellings to increase the aesthetic nature of their property (Avon-Heathcote Estuary Ihutai Trust 2005). Many estuarine ecosystems, including the salt marshes, battle for existence because of these conflicts.

1.1 Aims of Study

With continual activity and change occurring around and in the Avon-Heathcote Estuary, monitoring the diversity and extent of species in the salt marshes has become extremely important to ensure they can be managed in a sustainable manner. This comparative study uses research by McCombs and Partridge (1992) as a baseline to examine the state of the salt marsh vegetation in the Avon-Heathcote Estuary. To successfully research whether change has occurred in this estuary, vegetation surveys were repeated in the same locations as the McCombs and Partridge study. Global Positioning Systems (GPS) were used to create a detailed map of the margins of the estuary as well as the locations of the survey points. Throughout the report 'the estuary' will refer to the Avon-Heathcote Estuary.

1.2 Estuarine Environments and the Avon-Heathcote Estuary

Estuaries are complex systems due to the interaction between the ocean, fresh water, land, atmosphere and humans (Day et al. 1989). The estuarine environment provides habitat for different flora and fauna as well as having a significant role in maintaining the quality of coastal waters by managing water cycles and filtering sediments and pollutants out of the water (Masselink & Hughes 2005). They supply rich feeding grounds for fish as well as migrating birds.

Defining the term 'estuary' has been the subject of much literary debate over the last 50 years (Pritchard 1967). Because every estuary is slightly different this makes it difficult to have one overarching definition. The most commonly and widely accepted definition (Day et al. 1989, Macpherson 1978 and Rodrigo 1985) states that "*an estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage*" (Pritchard 1967, p3). This definition is appropriate for the Avon-Heathcote Estuary and will be used as the main definition throughout this report.

Being one of four major estuaries in the South Island of New Zealand, the Avon-Heathcote Estuary has national importance because of its high level of productivity, and biotic diversity and is one of Christchurch's most precious natural assets (Christchurch City Council 2001). The estuary was formed 450 years ago, making it geologically young (Harris 1992). From the air it resembles the shape of a stingray, with the Avon River being the tail and McCormacks Bay the head (Figure 1.1). The Avon and Heathcote Rivers flow from the north and southwest respectively, into the 8 km^2 coastal water body. Saline influence in the Avon River extends 8 km upstream to the Wainoni Street Bridge, and 11 km upstream in the Heathcote River to the Radley Street Bridge (Christchurch City Council 1980).

The Avon-Heathcote has been described as a shallow, largely intertidal (15% subtidal) estuary (Macpherson 1978). It has been classified as a bar-built (Griffin & Thomson 1992) and well-mixed estuary (Knox et al. 1973), fitting the former category since it was created with the formation of New Brighton Spit. The spit was created by southward moving longshore currents transporting sediments from the Waimakariri River (Avon-Heathcote Estuary Ihutai Trust. 2005). Bar-built estuaries are often very shallow and are not greatly affected by wave action (Pritchard 1967). The estuary has also been described as well-mixed (Knox 1973). Well-mixed estuaries have little or no vertical salinity gradients due to the high level of water mixing (Figure 1.2).

The Avon-Heathcote Estuary is also tide-dominated since the main water mixing process is controlled by the tides. In such estuaries, tidal processes and tidal energy often increase towards the landward end of the outer zone as a result of tidal shoaling (Masselink & Hughes 2005). It is because of this tidal influence that during low tides the estuary is drained except for the main channels from the Heathcote and Avon Rivers. The tide is the most important factor affecting the water level in the estuary. The relative energy distribution across different areas of tide-dominated estuaries change according to the position in the estuary. At the rivermouth, river tide currents dominate, whereas tidal energy is highest near the estuary opening to the sea. Wave influence generally stops half way up the estuary.

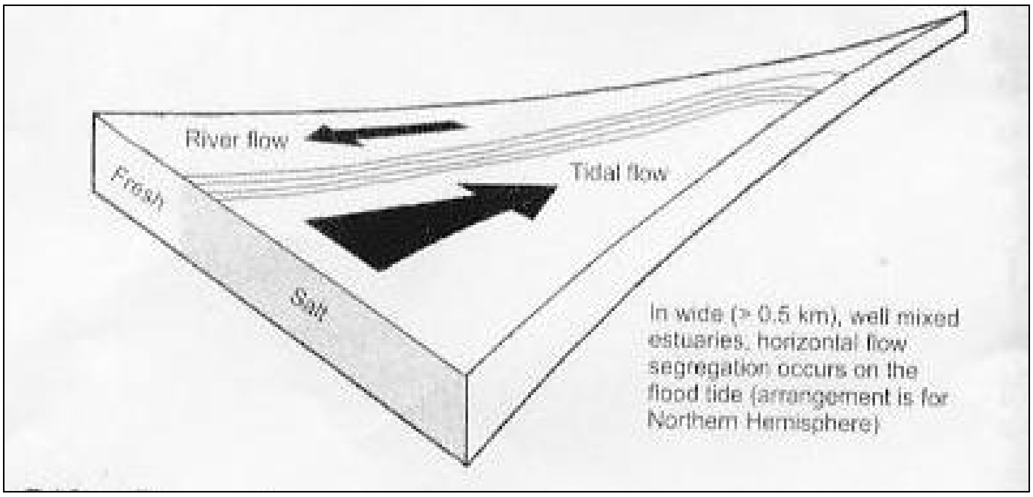

Figure 1.2 Flows of a well-mixed estuary (Masselink & Hughes 2005, p176)

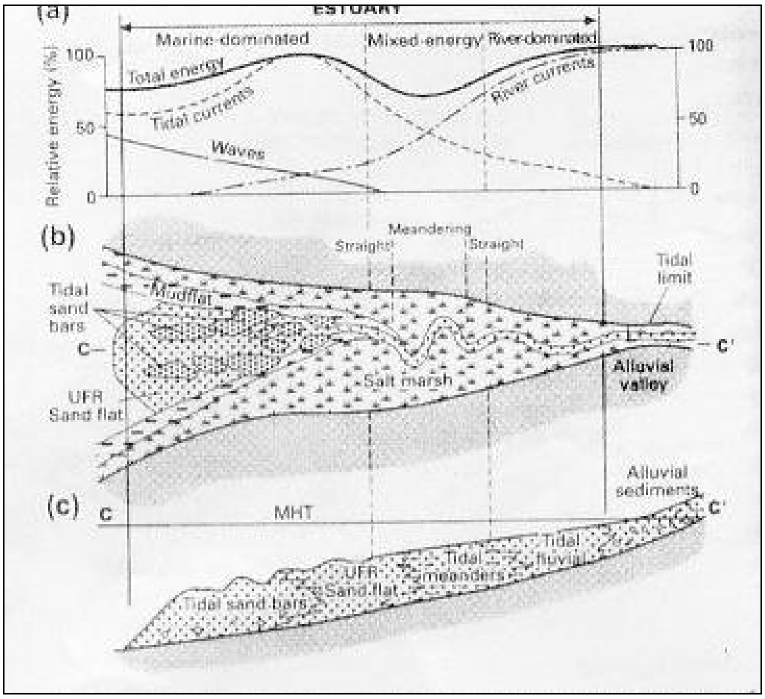

Figure 1.3 Energy distribution of a tide-dominated estuary (Masselink & Hughes 2005, p168)

Temporary waterbodies

Estuaries are temporary waterbodies, over geological time infilling and change in various complex environmental relationships influence this. Tidal currents and bathymetry, sediment size and supply, and rainfall all influence change within estuaries. An estuary's existence relies on a delicate balance between the flood (inward) and ebb (outward) flows of the tide. A change in speed of one of these flows can result in the estuaries demise, usually by infilling. If the flood tide is faster than the ebb more coastal sediment will be transported into, than out of, the estuary, leading to infilling. If the ebb flow is slower than the flood its velocity will not be strong enough to flush coastal sediment carried into the estuary on the flood out to sea, causing the estuary to infill. In combination with fluvial flows, the ebb currents must also be strong enough to remove catchment-eroded sediment delivered to the estuary by the river. As in many countries around the world, human activity has increased the level of infilling of many New Zealand estuaries through accelerated catchment erosion due to land use change, and modification of river flow regimes due to water abstractions and dam building (Wassilieff 2006).

Human impacts

The impact of human activity around the world has affected many estuaries. Twenty-two out of the world's thirty-two largest cities border estuaries, including New York and London (Day et al. 1989). Developments in hydraulic technology such as dredges and powerful pumps have impacted negatively on estuaries via operations such as infilling, draining of wetlands and canal dredging. Reclamation is another issue that has affected estuaries. All of these changes are linked to the intensified development of urban areas to cope with increasing populations. Important city management issues have impacted upon the Avon-Heathcote Estuary. For example the Christchurch Wastewater Treatment Plant had been discharging treated sewage into the estuary from the oxidation ponds over many decades (Christchurch City Council 2006). A project is now underway which will remove these discharges from the estuary, shifting them into the open-coast environment of Pegasus Bay. The Ocean Outfall project will use micro-tunnelling to lay pipe in the estuary bed. This method will have less impact on the flora and fauna of the estuary compared to the dredging methods first proposed for pipe construction (Moore 2006). The present study can be used a baseline to research whether the removal of discharge into the estuary from the oxidation ponds has a positive effect on the estuary's salt marsh communities. Additional discharges enter the estuary through runoff from the city centre into the Avon and Heathcote Rivers, carrying with them pollutants which are harder to reduce. These pollutants include zinc from galvanised roofs, house paint, storm water, and oil from roads (Avon-Heathcote Estuary Ihutai Trust 2005).

1.3 Estuarine Values

In addition to their vast ecological value, estuaries play an important role in society in terms of use for human recreational activity. These conflicting values can provide challenges to the management of estuarine environments. Human perception of wetlands and, specifically, of estuaries has given rise to this conflict. Historically estuaries have played an important role in New Zealand. Many along the country were chosen as settlement grounds for Maori and, later, Europeans. Their rich biological productivity meant they were ideal food gathering sites. Before the early 1960s estuaries were, however, typically underappreciated by European settlers, who looked upon them as wastelands to be drained and converted to farmland (Williams 1990). This was largely due to a lack of knowledge and understanding of estuarine ecosystems. As time passed and populations increased, towns and cities were built around these water ways because of the great uses they offered the people. This applied more pressure to the coast, resulting in many negative consequences. During the last few decades there has been an increase in estuarine related literature. The change in thinking brought about by the associated increase in public understanding of estuaries and human impacts on these fragile environments is evident today as salt marshes are now thought of as wetlands, rather than swamps. The late twentieth century change in name of Travis swamp to Travis wetland is one such example in the study area.

Recreation
As the Avon-Heathcote Estuary is in close proximity to the central city, 12 km to the east, it is extremely accessible to the Christchurch public (Williams 2005). The estuary offers lots of opportunities to Christchurch residents and visitors to the city. Pollution concerns aside, because the estuary is sheltered from waves it makes it an ideal location for wind surfing, kite surfing, sailing, kayaking, canoeing, swimming, fishing and bird watching (Christchurch City Council 2006). There are also areas around the estuary for walking and cycling.

Research
The Avon-Heathcote Estuary is used by local primary and secondary schools, and the University of Canterbury as a natural laboratory in which to explore interrelationships between plants and animals in estuarine environments (Morgans 1969). The University of Canterbury has conducted research on the estuary for over 40 years (Hutchison 1972; Knox et al. 1973; Rodrigo 1985; Thomsen 1999; and Alexander 2003). Knox et al. 1973 was one of the first reports to examine the ecology of the estuary. The Avon-Heathcote Estuary Ihutai Trust has recently put together an Ihutai

bibliography (Corliss 2006) containing 1200 research reports relating to the estuary. This is an excellent resource which may fuel more research focusing on the Avon-Heathcote Estuary.

Despite the above values, the estuary, its margins, and the plants and animals present in it have been the subject of degradation due to the level of development that has occurred around the estuary (Christchurch City Council 2001).

1.4 Estuarine ecology

The biota in estuarine environments is highly adaptable due to the unique characteristics of this environment. It is a very hostile environment for most plants because salt and tidal influences dominate (Wassilieff 2006). Plants that are able to grow in saline environments are called halophytes (Partridge & Wilson 1989). The animals and plants of the estuary must be able to cope with both saline and fresh water conditions, as well as with tidal fluxes, which cause the benthic biota to be submerged and exposed twice daily.

Salt marsh vegetation has decreased in New Zealand, mainly as a result of the increased human population and developments surrounding wetlands. Salt marshes now occupy less than 10% of the land they did prior to European settlement (Harris 1992). In the estuarine environment salt marsh vegetation is found above the mid-tide mark (Owen 1992).

Salt marsh vegetation can be divided into three zones relating to the different types of plants grown there. The lower marsh consists of tall sea rush or herbaceous plants. These include plants such as glasswort (*Sarcocornia quinqueflora*) and suaeda (*Suaeda novae-zelandiae*). These two plants are the only salt marsh plants which can grow in salinity levels greater than salt water. The herbaceous species make up the mid marsh zone, which also includes buck's horn plantain (*Plantago coronopus*) and bachelors button (*Cotula coronopifolia*). Lastly, in the upper marsh zone oioi (*Apodasmia similis*), tall fescue (*Schedonorus phoenix*) and coastal ribbonwood (*Plagianthus divaricatus*) are found (Jones & Marsden 2005). To live in a saline environment these plants have mechanisms in place to rid them of the salt they absorb. Glasswort (*Sarcocornia quinqueflora*) for example dilutes the salt water by storing it in their fleshy stems (McCombs and Partridge 1992).

2.0 Methods

Field work for this study was carried out in the summer of 2006 to 2007 from November to February, consisting of (1) detailed mapping of the margins of the Avon-Heathcote Estuary and (2) conducting vegetation surveys at the same locations examined in the McCombs and Partridge (1992) study. For both tasks *Trimble* Global Positioning Systems (GPS) were used to ensure that the data were recorded with a high level of spatial accuracy and to allow repeatability for future surveys. Both carrier and code phases were used, these refer to the particular signal used for timing measurements when collecting the data. Ground-based GPS receivers communicate with GPS satellites orbiting the Earth to accurately determine the receiver's location. GPS rely on the receiver having a clear view of the sky to communicate with multiple satellites at a time. This level of technology was not available at the time of McCombs and Partridge's (1992) study.

2.1 Mapping the Estuary Margins

A *GEO-XM* GPS unit was used in code phase to map the margins of the Avon-Heathcote Estuary. The *Trimble Geo-XM* unit used for this exercise is from the *GeoExplorer 2005* series and has a horizontal accuracy of 1-3 m (Justin Harrison, Laboratory, Field and Equipment Technician, Department of Geography, University of Canterbury, *pers. comm*. 2007).

This map of the estuary (Figure 3.1) is the first to be created with such a detailed wealth of shoreline information and in a correctly geo-referenced format and, as such, will be a great asset to the Avon-Heathcote Estuary. It shows where hard edges have been built and the areas of natural shoreline that remain. Erosion was also mapped to help explain why some areas of salt marsh have disappeared. The area of salt marsh coverage was also captured and mapped to provide a clear visual of where the salt marsh is located today. It was important to map the salt marsh using GPS, as aerial photographs do not distinguish salt marsh from other vegetation types. When capturing the data (Figure 2.1) emphasis was placed on getting as close to the feature as possible to achieve a high degree of spatial accuracy, but in some areas this was difficult due to large trees obstructing the sky view of the GPS unit.

A data dictionary was created using the software programme *Pathfinder Office 3.10* and then transferred to the GPS receiver before fieldwork was undertaken. All of the different elements found in the field were added as point, line or area features. Using a data dictionary makes the resulting map far more accurate as each feature has a different name and symbol making it easy to distinguish between different features.

Figure 2.1 Kimberly capturing the margins of the Avon-Heathcote Estuary using a *Trimble Geo-XM* unit

ArcGIS software was used to create the map according to the following standard procedures. Four aerial photographs (Gifted to University of Canterbury by Christchurch City Council 1992), taken in the mid-1990s, were used as the visual base of the map. Once all of the 37 datasets were added, digitalising occurred to tidy up the map by removing sliver polygons. This makes the map easier to read and understand. All of the same features were then merged together to create one layer for each feature using suitable symbols. The map gives a clear visual understanding of where the current salt marsh vegetation is located and the areas of natural and hard edges of the estuary.

2.2 Vegetation Surveys

Due to the comparative nature of this report the same survey sites examined by McCombs and Partridge (1992) were used in the present study (Figure 2.2). Since a GPS was not used by McCombs and Partridge (1992) it was difficult and time consuming to obtain a high degree of accuracy when finding the correct location of each 1992 survey site. However, becuase GPS has been used in this study it will be much easier and quicker for future researchers to conduct vegetation surveys in the same locations, making this research an excellent baseline for future monitoring of the salt marshes around the Avon-Heathcote Estuary.

A *Trimble Geo-XT* unit was used in carrier phase to capture the vegetation survey sites (Figure 2.3). This unit was used instead of the *Geo-XM* because it is able to operate in carrier phase. Using the carrier frequency significantly improves the precision of GPS to a horizontal accuracy of 0.1-0.5 m (Justin Harrison *pers. comm.*) A high degree of accuracy was required for this task so that future vegetation surveyors can find the exact sites used in this study for accurate comparisons of vegetation change. To work in carrier phase the GPS needs to be locked with at least four satellites for a period of time, if the lock is lost it can add valuable time out in the field waiting for carrier phase to be established again. This study used 10 minutes as the minimum time for the position to be calculated.

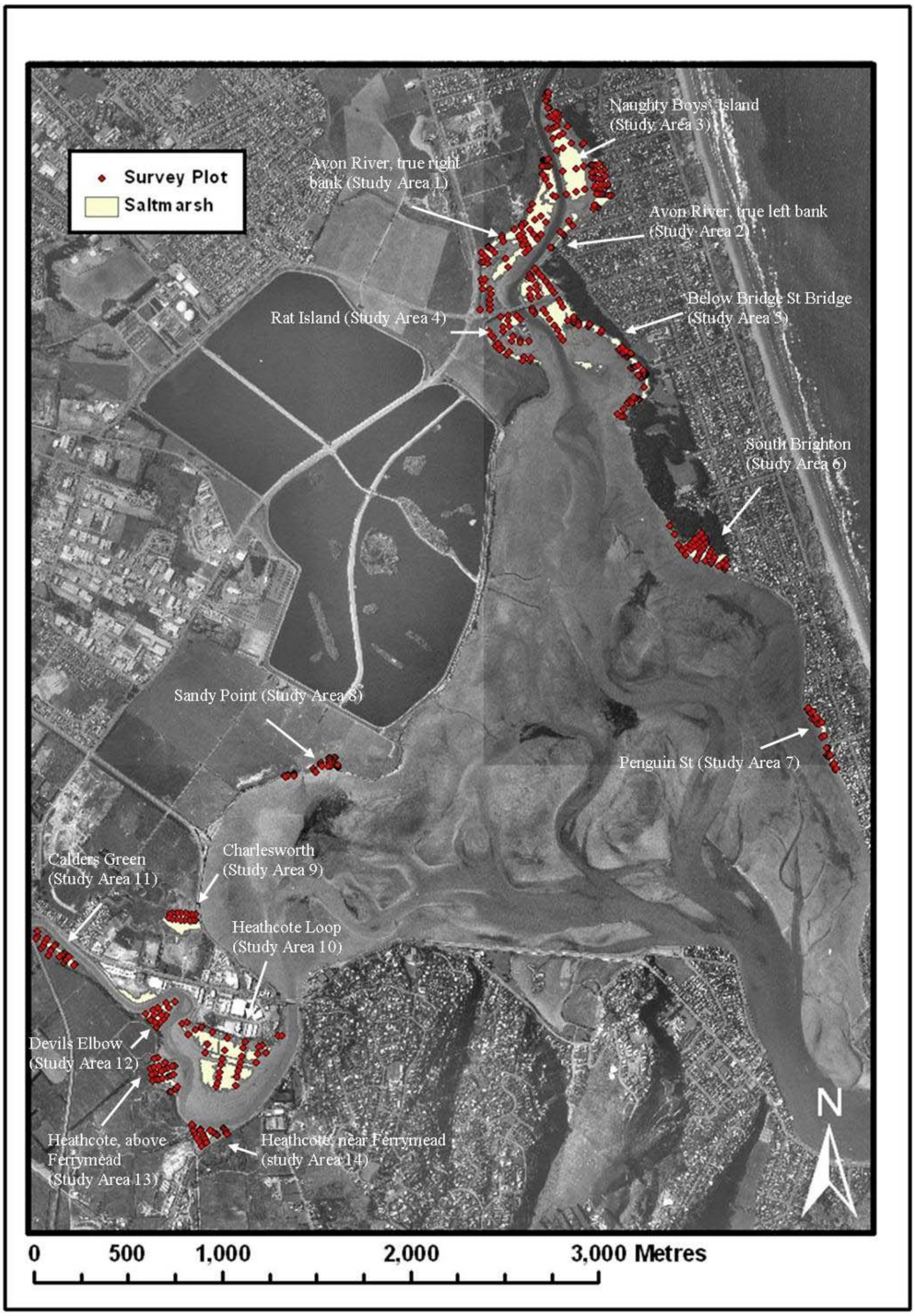

Figure 2.2 Map showing the 14 study areas surveyed

Figure 2.3 Kimberly capturing a survey site using a *Trimble Geo-XT* unit

Figure 2.4 Assistant (Jason) pegging out vegetation survey site

Appendix 1 contains the survey areas and the site codes for each location surveyed. Note that some sites were relabelled with different codes in this study to ensure that each individual survey site has a unique identity. In addition to each survey plot having its own code, it has also been geo-referenced. The x and y coordinates for each survey site have been recorded in Appendix 2. Once the location of each survey site had been captured using the GPS, the vegetation surveys were completed. 2 m x 2 m quadrats were pegged out (Figure 2.4) and all of the species in the quadrat were recorded on survey sheets using vegetation codes. These survey sheets used were those used in 1992. Two people conducted these surveys together in the field, with the first identifying the plants present in a quadrat, while the second person recorded the codes of the species. This system work well and proved to be very efficient.

2.3 Accuracy Issues

Although GPS devices have the potential to be highly accurate, there are many factors that can affect the level of precision. While capturing features in some areas around the estuary, patches of thick tall trees obstructed the signal from the GPS with the satellites. This caused the Position Dilution of Precision (PDOP) to increase. The lower the PDOP values, the more accurate the GPS positions captured. The areas where accuracy was an issue was in the study areas 5 and 6. The mapping of the margins was affected whereas capturing the survey plots was not.

Inaccuracies were also experienced when trying to locate the exact survey plots from the 1992 study. This may have resulted in some survey sites being located in the incorrect position in this study. However with the use of GIS any future studies will not experience this problem.

2.4 Data Processing

Differential Correction
Each day after the data were collected differential correction was performed using the *Pathfinder Office 3.10* software to further increase its spatial accuracy (*Trimble* 2007). Comparisons are made between data from two receives during this correction process: the mobile receiver carried by the surveyor is compared to another, stationary, receiver termed the base station. The University of Canterbury's base station was used in the study. When using carrier phase the base station needs to be less than 50 km away from where the data capturing is occurring (*Trimble* 2007). The mobile receiver captures all the features out in the field and is termed the rover. Once the data were differentially corrected it was then exported into *ArcGIS* and added as layers.

SPSS
The software package SPSS was used for the analysis of the vegetation survey data. The species presence/absence data for the plots were analysed as a single data set. Salt marsh sites where the vegetation has disappeared between 1992 and 2007 due sediment infilling were removed because SPSS does not recognise variables which contain no value. Direct comparisons were then made between communities of changes in the vegetation. Cluster analysis was used to compare the plot/species data. The sorting strategy used was Jaccard (Williams et al. 1973): that is, between-group linkage and similarity was measured. Twelve site clusters were eventually specified after outlier removal. The initial analyses separated out a number of data outliers, most representing odd sites around the margin. These are listed as 'outlier' in further tables and no further interpretation of their composition is included. These were progressively removed from the analysis until the minimum site group size was 3. The analysis presented still has uneven group sizes, with three groups being represented by a large number of plots. In particular one vegetation type (3) is particularly diverse, but was not analysed further as it is also one of the most dynamic and further subdivision was not expected to be especially revealing.

3.0 Results

3.1 Mapping of the Avon-Heathcote Estuary

In order to conduct future saltmarsh studies around the Avon-Heathcote Estuary, it is important to have a detailed map. The map created in this study is the first to be created of its kind in such detail in New Zealand. Figure 3.1 illustrates a small-scale overview map of all 14 study areas within the estuary. It was created in ArcGIS using the GPS data captured using *Trimble* Rovers. As the map is geo-referenced it makes it an excellent resource for future comparative research. The map shows that there is a high level of built edges around the estuary which emphasises the human impact on the Avon-Heathcote Estuary. The southern and eastern margins of the estuary are mostly made up of built structures, such as ramps, concrete walls and rubble. The western side, on the other hand, is mostly natural estuary margins. The map was used to calculate the total area of salt marsh vegetation growing in the estuary to be 372163 m^2 (0.37 km^2). This figure can be used in future studies to monitor the change in salt marsh area.

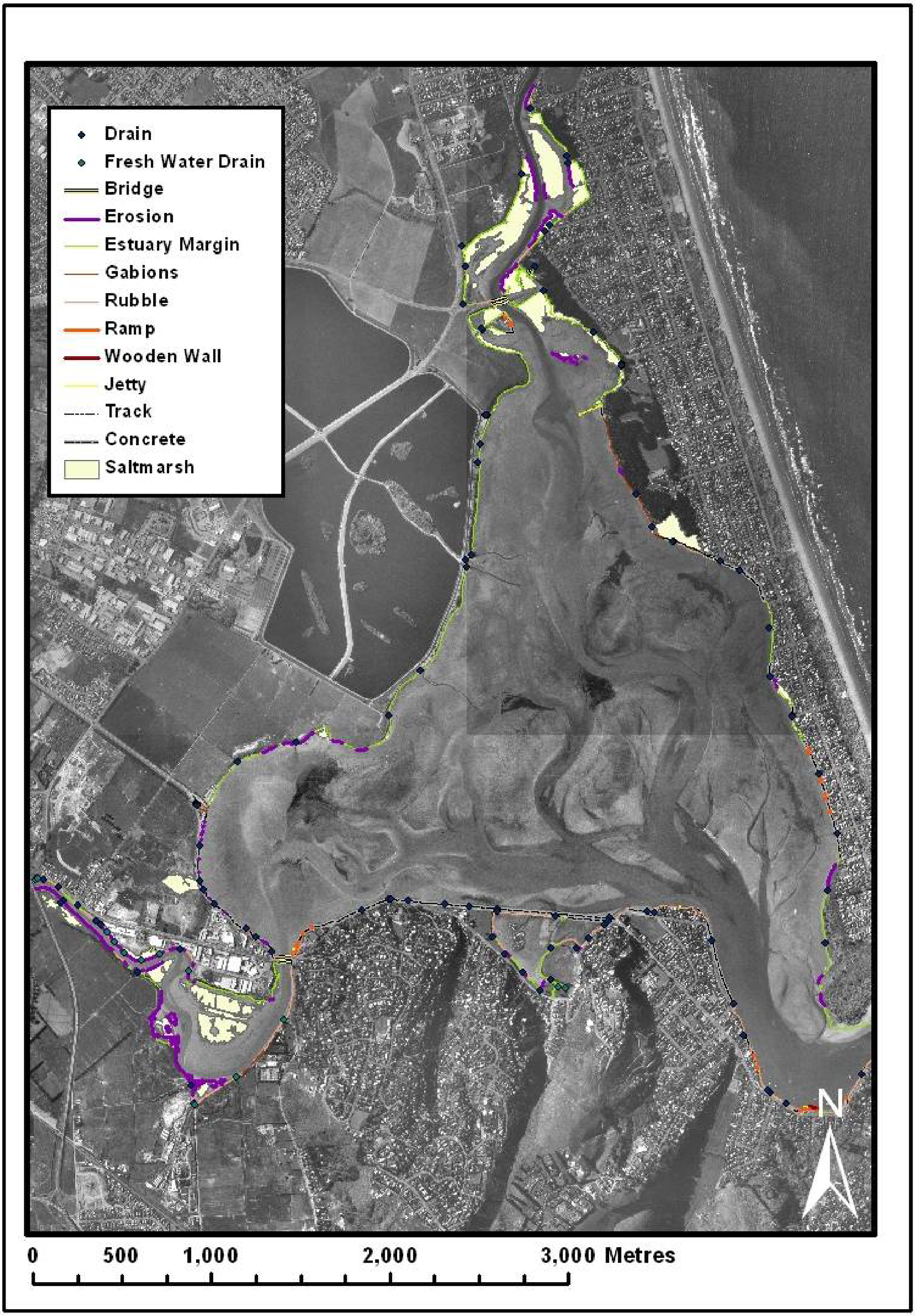

Figure 3.1 Map showing the materials which make up the margins of the Avon-Heathcote Estuary and the locations of the salt marshes

3.2 Vegetation Type Descriptions and Occurrence

Following is a description of the 12 main vegetation types found from the ecological surveys of the salt marshes around the Avon-Heathcote Estuary and of any changes in their occurrence noted between the 1992 and 2007 surveys. In the title of each of the following vegetation type sections the numbers in the brackets after each name indicate the number of sites that fell into each vegetation type from the 1992 and 2007 studies combined (e.g. if 5 type 1 examples were found in 1992 and 7 type 1 examples were found in 2007, then the total in brackets would be 12).

Figure 3.2 Oioi (*Apodasmia similis*)

Type 1. Oioi Rushland (340 sites)

This is a simple vegetation type comprising oioi (*Apodasmia similis*) (Figure 3.2), often in association with sea rush (*Juncus krausii*) and/or coastal ribbonwood (*Plagianthus divaricatus*). Figure 3.3, 1992 shows where the sites that were classified as community type 1 went to in 2007. Of the 162 original Type 1 sites sampled by McCombs and Partridge (1992), 83% remained the same type in 2007, with the majority of those that changed turning into Salt marsh Herbfield (Type 3). There has been an increase of 13 sites that have joined Type 1. The 2006 graph shows where the sites in community 1 have come from. A high proportion has come from Sea Rush Rushland (Type 2). The main changes are from Salt marsh Herbfield (Type 3) and Native Musk Herbfield (Type 8) which has been virtually replaced by the increase in oioi (*Apodasmia similis*) species.

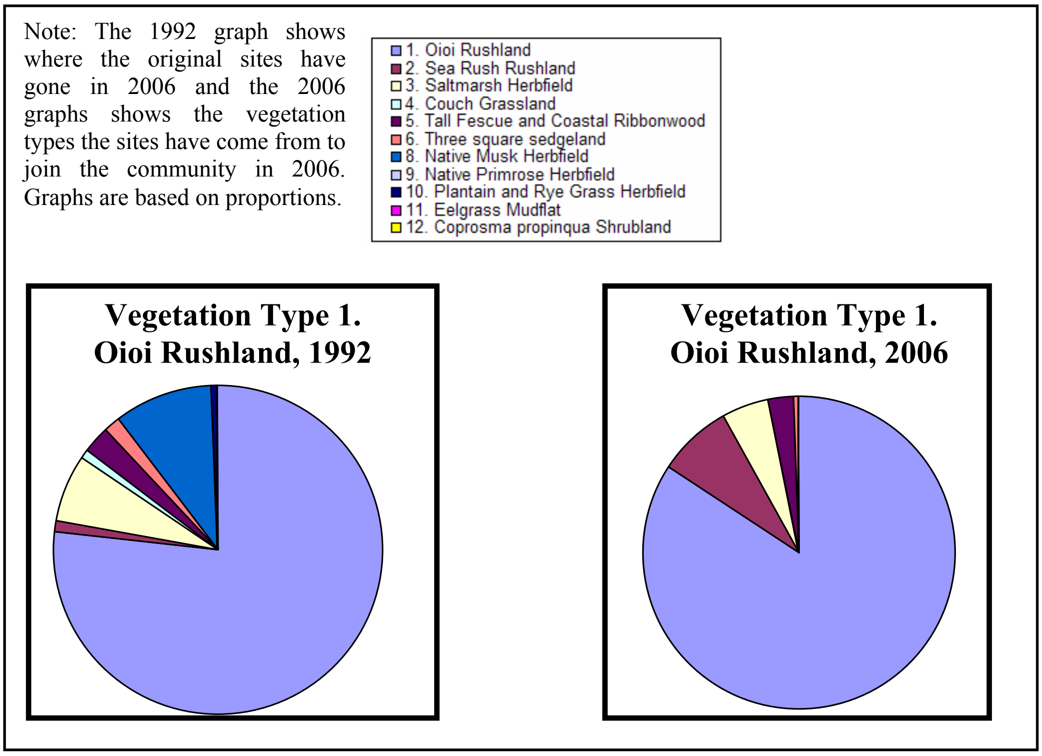

Figure 3.3 Pie graphs showing distributions of vegetation types in 1992 and 2006.

Type 2. Sea Rush Rushland (205 sites)

This vegetation type mainly consists of one species, this being sea rush (*Juncus krausii*) (Figure 3.5) however, coastal ribbonwood (*Plagianthus divaricatus*) is also present in some sites.

The 1992 graph (Figure 3.4) shows that this is the second most stable vegetation type as 83% of the original plots have remained the same. The only change has been a few plots that have become Salt marsh Herbfield (Type 3) (Figure 3.4 2006). However, quite a few plots have changed in the reverse direction to become this vegetation, including some that were Oioi Rushland (Type 1). Also, quite a few former plots of this vegetation have become mudflats with no salt marsh species.

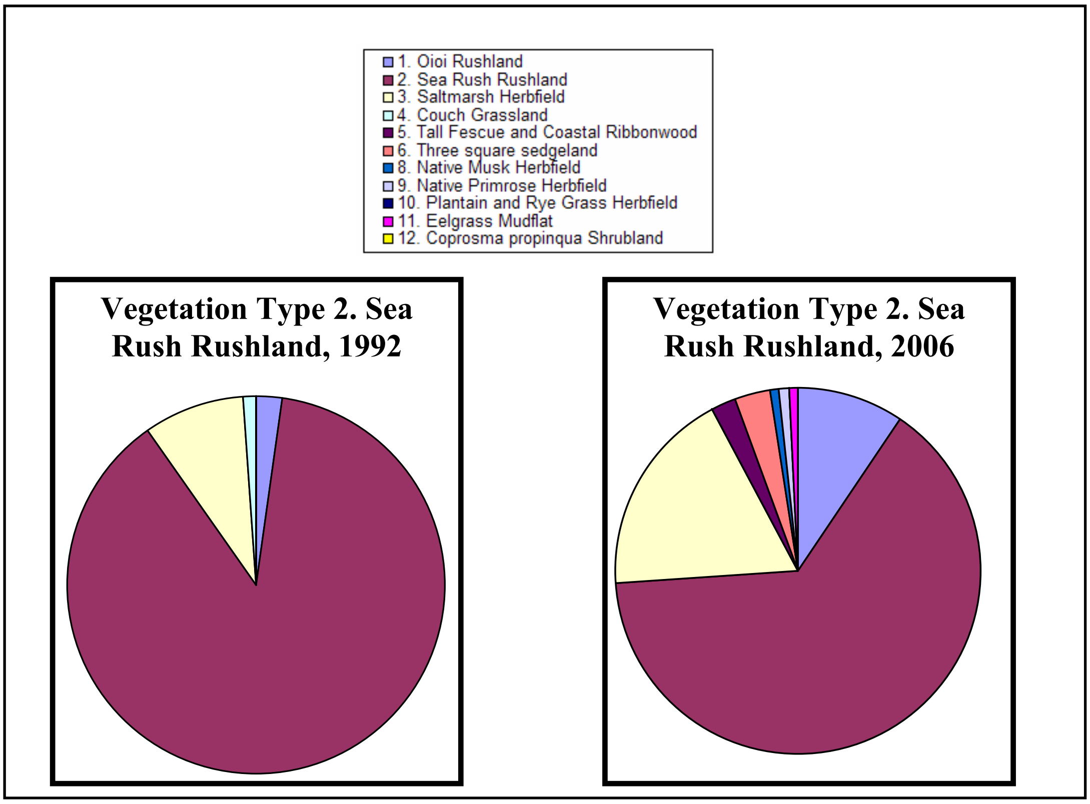

Figure 3.4 Pie graphs showing distributions of vegetation types in 1992 and 2006

Figure 3.5 Sea rush (*Juncus krausii*)

Figure 3.6 Glasswort (*Sarcocornia quinqueflora*)

Figure 3.7 Orache (*Atriplex prostrata*)

Figure 3.8 Salt grass (*Puccinellia stricta*)

Figure 3.9 Selliera (*Selliera radicans*)

Type 3. Salt marsh Herbfield (200 sites)

This comprises a diversity of salt marsh herbs along with some larger plants. Glasswort (*Sarcocornia quinqueflora*) (Figure 3.6) is the most common, along with buck's horn plantain (*Plantago coronopus*), orache (*Atriplex prostrata*) (Figure 3.7), native primrose (*Samolus repens*), salt grass (*Puccinellia stricta*) (Figure 3.8) and Selliera (*Selliera radicans*) (Figure 3.9). Taller plants of oioi (*Apodasmia similis)*, coastal ribbonwood (*Plagianthus divaricatus*) and sea rush (*Juncus krausii*) are also found.

47% of the original plots still contain the original composition found in 1992. Most of the changed sites have been replaced by Sea Rush Rushland (Type 2) or Oioi Rushland (Type 1). However there are also some reversals, for example coastal ribbonwood (*Plagianthus divaricatus*) now dominates and has created a new vegetation type (Type 7). This was not recorded in the original sampling. Couch Grasslands (Type 4) and Sea Rush Rushlands (Type 2) have also changed to this vegetation type.

Type 4. Couch Grassland (24 sites)
This vegetation type occurs in the former upper marsh zone and comprises thick swards of couch (*Elytrigia repens*). Remnant sea rush (*Juncus krausii*)is found in places and creeping bent (*Agrostis stolonifera*) is also common. This type has changed considerably since the first study in 1992, with only 13% of the original sites still characterised by this vegetation. Many of the original Type 4 sites were found now to be Salt marsh Herbfield (Type 3), but an almost equal number of other sites have changed into Couch Grassland (Type 4). The latter result may, however, represent an error in surveying due to the difficulty of finding the 1992 survey sites.

Figure 3.10 Tall fescue (*Schedonorus phoenix*)

Type 5. Tall Fescue and Coastal Ribbonwood (49 sites)
The dominant upper marsh vegetation comprises a mix of exotic tall fescue (*Schedonorus phoenix*) (Figure 3.10) and native coastal ribbonwood (*Plagianthus divaricatus*), along with flax (*Phormium tenax*), couch (*Elytrigia repens*) and taupata (*Coprosma repens*). Only 35% of the original Type 5 plots remained as the same vegetation type. Those that have changed become Sea Rush Rushland (Type 2) or

Oioi Rushland (Type 1). Additions to this vegetation have come from Couch grassland (Type 4) and Oioi Rushland (Type 1).

Figure 3.11 Three square (*Schoenoplectus pungens*)

Type 6. Three square sedgeland (45 sites)
Three square (*Schoenoplectus pungens*) (Figure 3.11) dominates this vegetation type. Raupo (*Typha orientalis*) and tall fescue (*Schedonorus phoenix*)also occur in Type 6 plots at the site of a freshwater spring in what is known as Raupo Bay. Otherwise associated species are typically few where this vegetation occurs on mudflats. This vegetation remained in 13 or 59% of the 22 original type 6 plots. Most of the losses were to oioi (Type 1) and sea rush (Type 2) rushland. The original *Coprosma propinqua* Shrubland (Type 12) has been totally replaced by this Type 6 vegetation. It is suspected that this land-based vegetation has invaded and transformed the mudflats, which have become colonised by three square.

Type 7. Coastal Ribbonwood Shrubland (6 sites)
Coastal ribbonwood (*Plagianthus divaricatus*) (Figure 3.12) occurs with few associated salt marsh species. However, this tall shrub has allowed the aggressive reed canary grass (*Phalaris arundinacea*) to colonise. This vegetation type was not recorded in the original sampling, and has appeared as a novel type. The 6 sites where it was found have changed from Salt marsh Herbfield (Type 3). Type 7 owes its origin to Salt marsh Herbfield (Type 3) presumably by a thickening of the shrubs.

Figure 3.12 Coastal ribbonwood (*Plagianthus divaricatus*)

Figure 3.13 New Zealand musk (*Mimulus repens*)

Figure 3.14 Suaeda (*Suaeda novae-zelandiae*)

Figure 3.15 Bachelors button (*Cotula coronopifolia*)

Type 8. Native Musk Herbfield (24 sites)
This vegetation type is somewhat similar to the Salt marsh Herbfield (Type 3) but with the addition of native musk (*Mimulus repens*) (Figure 3.13) instead of glasswort (*Sarcocornia quinqueflora*), and other more salt tolerant herbs such as suaeda (*Suaeda novae-zelandiae*) and Bachelors button (*Cotula coronopifolia*) (Figures 3.14-3.15). Native musk is indicative of brackish conditions. This vegetation type has all but disappeared from the estuary, with its distribution declining from 5% of the total

number of original sites to a mere 0.5% of the 2007 sites. It has been replaced almost exclusively by Oioi Rushland (Type 1).

Type 9. Native Primrose Herbfield (4 sites)
This rather depauperate and rare vegetation type is characterised by the presence of native primrose (Figure 3.16), without its normal salt marsh associates. It was present during the original 1992 sampling. Most of these sites were found to now carry additional species of other salt marsh types such as sea spurrey (*Sperglaria media*) and New Zealand celery (Figures 3.17-3.18).

Figure 3.16 New Zealand primrose (*Samolus Repens*)

Figure 3.17 Sea spurrey (*Sperglaria media)*

Figure 3.18 New Zealand celery (*Apium prostratum*)

Figure 3.19 Buck's horn plantain (*Plantago coronopus*)

Type 10. Plantain and Rye Grass Herbfield (9 sites)

The presence of buck's horn plantain (*Plantago coronopus*) (Figure 3.19) and ryegrass (*Lolium perenne*) indicates disturbed sites and, often, soil dumped on to the salt marsh. This vegetation was only present during the original sampling. Most of the 9 plots had by 2007 become Salt marsh Herbfield (Type 3).

Type 11. Eelgrass Mudflat (3 sites)

Eelgrass (*Zostera capricorni*) is a marine angiosperm found in the estuary as a sward below the salt marsh zone, but occasionally mixing with it. The three sites recorded in the first survey no longer had any vegetation present, with two sites now colonised by other salt marsh vegetation, either sea rush (*Juncus krausii*) or three square (*Schoenoplectus pungens*).

Type 12. Coprosma propinqua Shrubland (3 sites)

This is essentially a freshwater wetland with the shrub *Coprosma propinqua* along with raupo and the sedge *Schenoplectus vallidus*. The sites present in the first survey were no longer there and have been replaced by Three Square Sedgeland (Type 6). This suggests that the area has been eroded and the new vegetation established on the resulting mudflats.

3.3 Plant Species Occurrence in the 12 Vegetation Types

Table 3.1 contains a list of the different species which are present in each of the vegetation types found in the Avon-Heathcote Estuary. Species found in only one site have been left off the list because they were considered outliers. The species included in the list are regarded as being the most common salt marsh species found in the Avon-Heathcote Estuary between 1992 and 2007. The table numbers represent percentage frequencies, with 100 indicating that a plant species was present in all of the plots in that vegetation type. The numbers in bold represent species with a percentage frequency in a particular vegetation type greater than 70%, meaning that they are the dominant species in that vegetation type. The second row includes the number of sites found of each vegetation type. This table shows that vegetation Types 1 and 2 were the most dominant in the Avon-Heathcote Estuary. The species order was generated by an inverse classification of site date.

Table 3.1 Percentage frequency of the different plant species found in the 12 vegetation types

Vegetation Types		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Number of Plots		340	205	200	24	49	45	6	24	4	9	3	3
Apodasmia similis	Oioi	**97**		9		8			17				
Juncus krausii	Sea rush	34	**100**	54	42	10	18	50	33				
Plagianthus divaricatus	Coastal ribbonwood	41	21	40		**76**	7	**100**			22		
Schedonorus phoenix	Tall fescue	19	8	19	21	**98**	53				22		
Atriplex prostrata	Orache		5	40		16	7						
Suaeda novae-zelandiae	Suaeda or sea blite		8	25									
Puccinellia stricta	Dalt grass			39									
Parapholis incurva	Sickle grass			12									
Elytrigia repens	Couch		5	21	**96**	39							
Apium prostratum	NZ celery			11		22				25			
Sarcocornia quinqueflora	Glasswort			**72**							67		
Plantago coronopus	Buck’s horn plantain			60	8						**78**		
Lolium perenne	Perennial ryegrass			5							**89**		
Spergularia marginate	Sea spurrey			17					21	25			
Leptinella dioica	Cotula			7					17		22		
Samolus repens	NZ primrose			29					17	**100**			
Agrostis stolonifera	Creeping bent			10	54								67
Selliera radicans	Selliera			30					46				
Lupinus arboreus	Tree lupin				8								
Plantago lanceolata	Narrow-leaf plantain				12								
Crepis capillaris	Hawksbeard				8								
Achillea millefolium	Yarrow				12								
Malva sylvestris	Dwarf mallow				8								
Holcus lanatus	Yorkshire fog				21						22		
Vicia sativa	Vetch				21	6		33					
Phormium tenax	Lowland flax					24	9						33

Ficinia nodosa	Knobby clubrush					16	7			25			
Coprosma repens	Taupata					24							
Schoenoplectus pungens	Three-square					10	**84**		12			33	
Typha orientalis	Raupo						40						67
Spartina anglica	Cord grass						9						
Iris foetidissima	Stinking iris						7						
Rubus fruticosus agg.	Blackberry												33
Phleum pratense	Timothy							**83**					
Phalaris arundinacea	Reed canary grass				8			**100**					
Mimulus repens	NZ musk			7			7		**96**				
Cotula coronopifolia	Bachelors button								50				
Poa cita	Silver tussock								17				
Chrysanthemoides monilifera	Boneseed								13				
Galium aparine	Cleavers										22		
Zostera capricorni	Eel grass											**100**	
Dactylis glomerata	Cocksfoot										33		67
Coprosma Propinqua	Mingimingi												**100**
Schoenoplectus vallidus	Lake clubrush												67
Carex secta	Tall tussock sedge												67
Phymatosorus Diversifolius	Hound's tongue fern												33
Salix fragilis	Crack willow												33

Table 3.2 Transition matrix of 1992 and 2006 Vegetation Types

		2006-2007 Vegetation Types											**Number of Sites**	**Index of Stability**
		1	2	3	4	5	6	7	8	9	Outliers	Gone		**(0-1)**
1992-1993 Vegetation Types	1	**134**	12	8	0	4	1	0	0	0	1	2	162	0.83
	2	2	**82**	8	1	0	0	0	0	0	0	6	99	0.83
	3	12	23	**50**	4	1	1	6	0	0	1	8	106	0.47
	4	1	0	9	**2**	4	0	0	0	0	0	0	16	0.13
	5	5	3	8	0	**11**	3	0	1	0	0	0	31	0.35
	6	3	4	0	0	0	**13**	0	0	1	0	1	22	0.59
	8	17	1	1	0	0	1	0	1	0	0	1	22	0.05
	9	0	1	2	0	0	0	0	0	0	0	0	3	0
	10	1	0	5	0	1	0	0	0	0	0	2	9	0
	11	0	1	0	0	0	1	0	0	0	0	1	3	0
	12	0	0	0	0	0	3	0	0	0	0	0	3	0
	Outliers	0	0	0	0	1	0	0	0	0	4	2	n/a	n/a
													Overall	0.63
													Stability	

Table 3.2 is a transition matrix showing how the vegetation types have changed since 1992. Each of the values indicates the number of sites in each vegetation type. An example of how this table is read is as follows: the number of sites present in vegetation Type 1 in 2006-2007 is calculated by adding together all the vales vertically under the Type 1 heading. To calculate the values for 1992 the same is done except the values are added horizontally. Also the values in the columns show which vegetation types the sites have come from to join the new vegetation type in 2006-2007, and the rows show what 1992 sites have moved into different communities in 2006-2007.

The index of stability is the proportion of sites in each community that have remained the same. Values in bold show the number of sites that have remained the same vegetation type. The overall level of salt marsh stability in the Avon-Heathcote Estuary was calculated by adding together all the bold values and dividing it by the total number of sites. This revealed a 63% level of stability. The main finding from this table is that Oioi Rushland (Type 1) and Sea Rush Rushland (Type 2) are the most stable community types since they have changed the least over the last fourteen years.

3.4 Survey Study Areas

The total area of salt marsh present in the Avon-Heathcote Estuary as determined from the GPS measurements was 372163 m^2 (0.37 km^2). This includes all of the main study areas described below, as well as all other smaller areas of salt marsh around the margins of the estuary.

Figure 3.20 Salt marsh on the Avon River true right bank study area 1

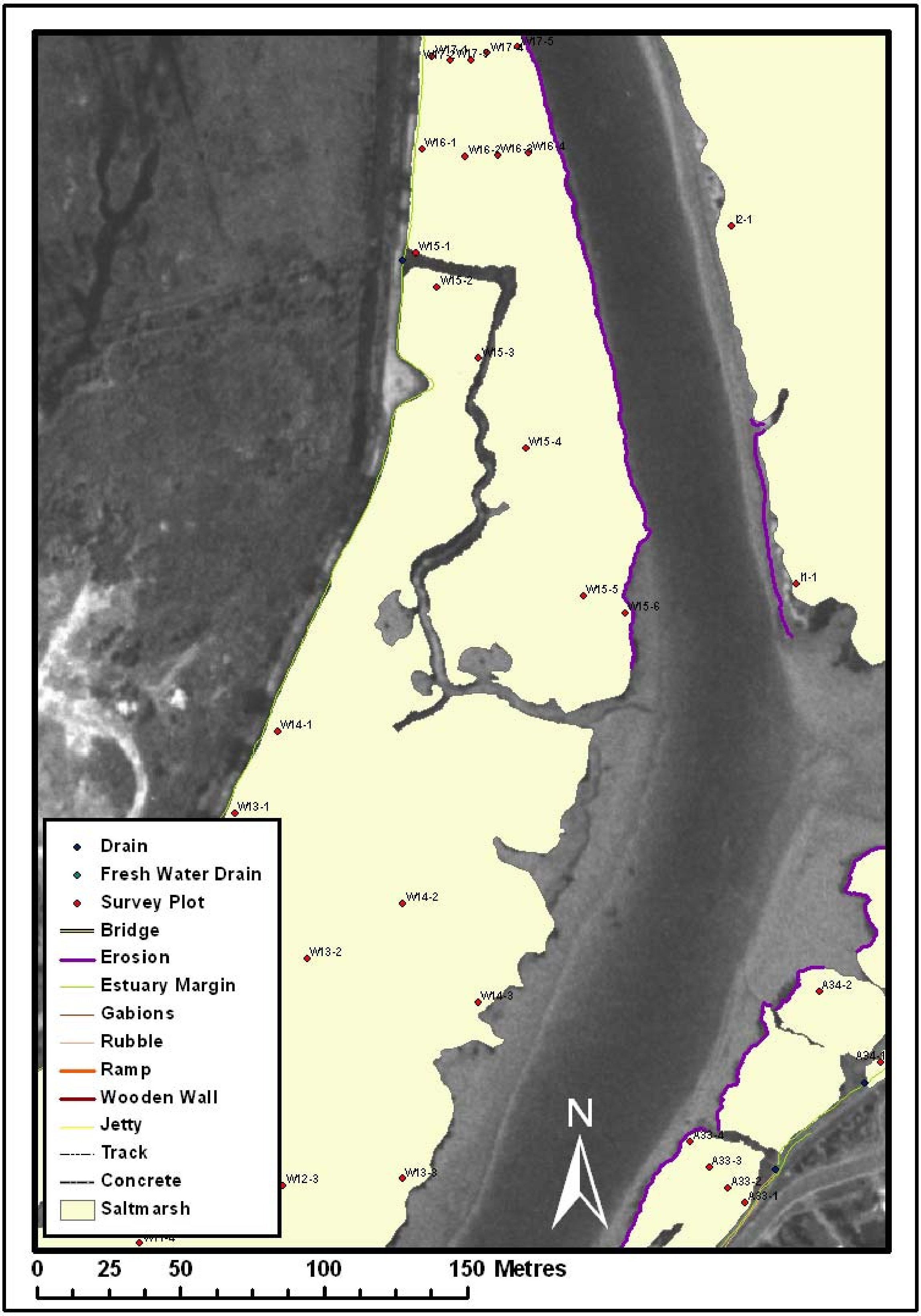

Figure 3.21 Salt marsh map for the Avon River true right bank northern part of area 1

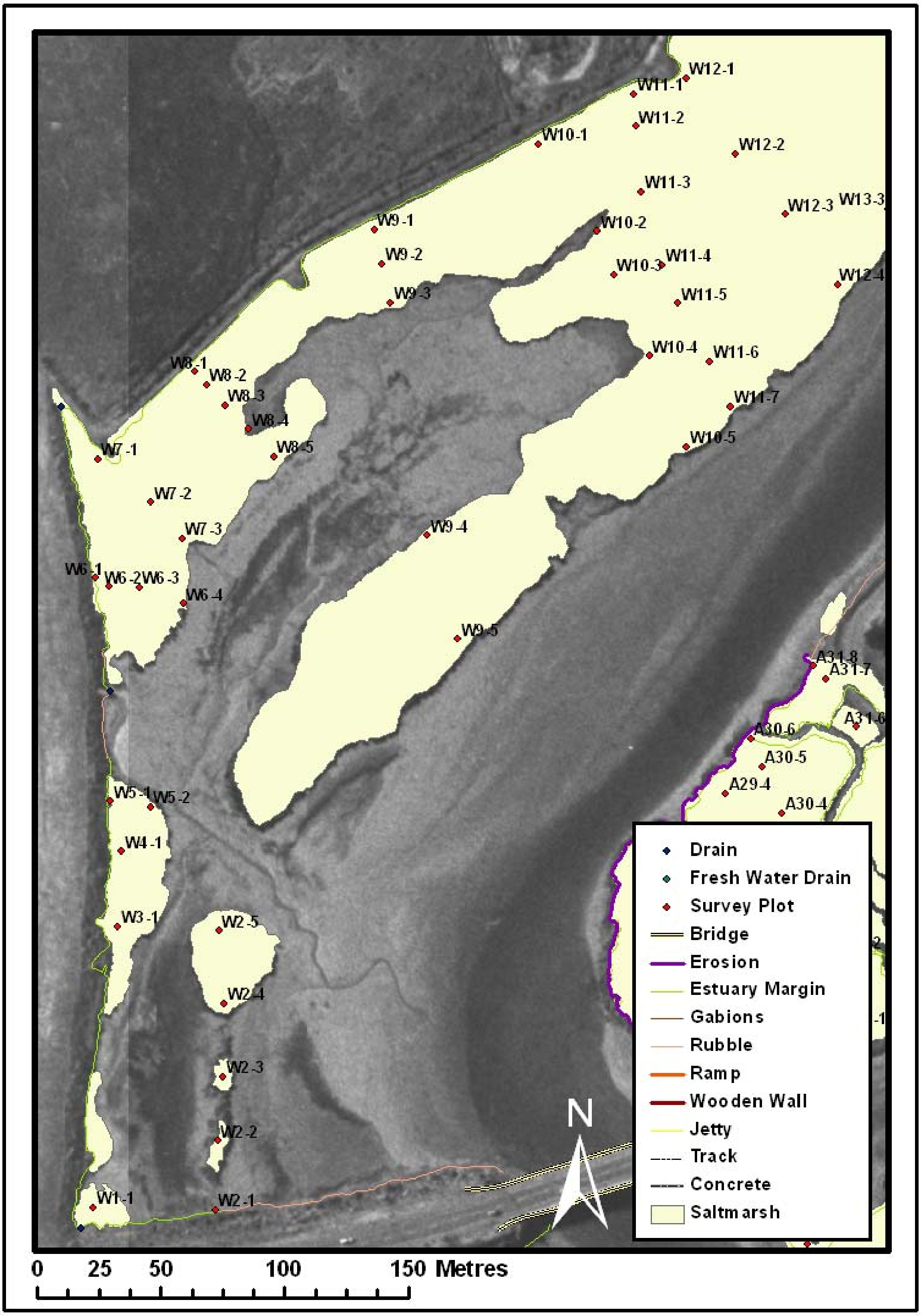

Figure 3.22 Salt marsh map for the Avon River true right bank southern part of area 1

Avon River true right bank study area 1

Located on the true right bank of the Avon River (Figures 3.20-3.22), this part of the estuary contains the largest extent of salt marsh (70970 m^2). Only one salt marsh site no longer had any vegetation present in this area. W8-4 changed to an area of mud (see location in Figure 3.22). This vegetation may have disappeared due to scouring on the ebb flow. As tidal waters drain from the estuary, erosive energy is focussed on the vegetation in the alcove that appears near W8-4 (Figure 3.22). In the future it is expected that the vegetation present in site W8-5 will disappear too. This was found to be one of the most stable areas in the Avon-Heathcote Estuary, with Oioi rushland (Type 1) being the most dominant vegetation type both in 1992 and 2006. Sea Rush Rushland (Type 2) was also found in 2006, but only is certain areas.

Avon River true left bank, study area 2

This large area of salt marsh (53537 m^2) is very diverse with six vegetation types present: Types 2, 3, 5, 6, 8 and 9 (Figures 3.23-3.26). Only one site has vegetation which had disappeared since 1992, A47-4, and this change likely being due its location. The site was located on the point of a bend where the Avon River flows into the two channels near Naughty Boys' Island (Figure 3.24). Constant pressure from river flows may have slowly eroded away the small herbaceous plants present. The most dominant vegetation type present in this area of the estuary was Oioi Rushland (Type 1) in both 2007 and 1992. Table 3.3 shows that oioi (*Apodasmia similis*) has taken over areas where vegetation Types 3, 4, 8 used to exist. This trend is seen throughout the Avon River.

Table 3.3 Transition matrix of the Avon River true left bank study area 2

		2006-7		
		1	2	3
1992-3	1	**41**	2	1
	2	0	**1**	0
	3	3	0	**1**
	4	1	0	0
	8	9	1	0

Figure 3.23 Avon River true left bank study area 2

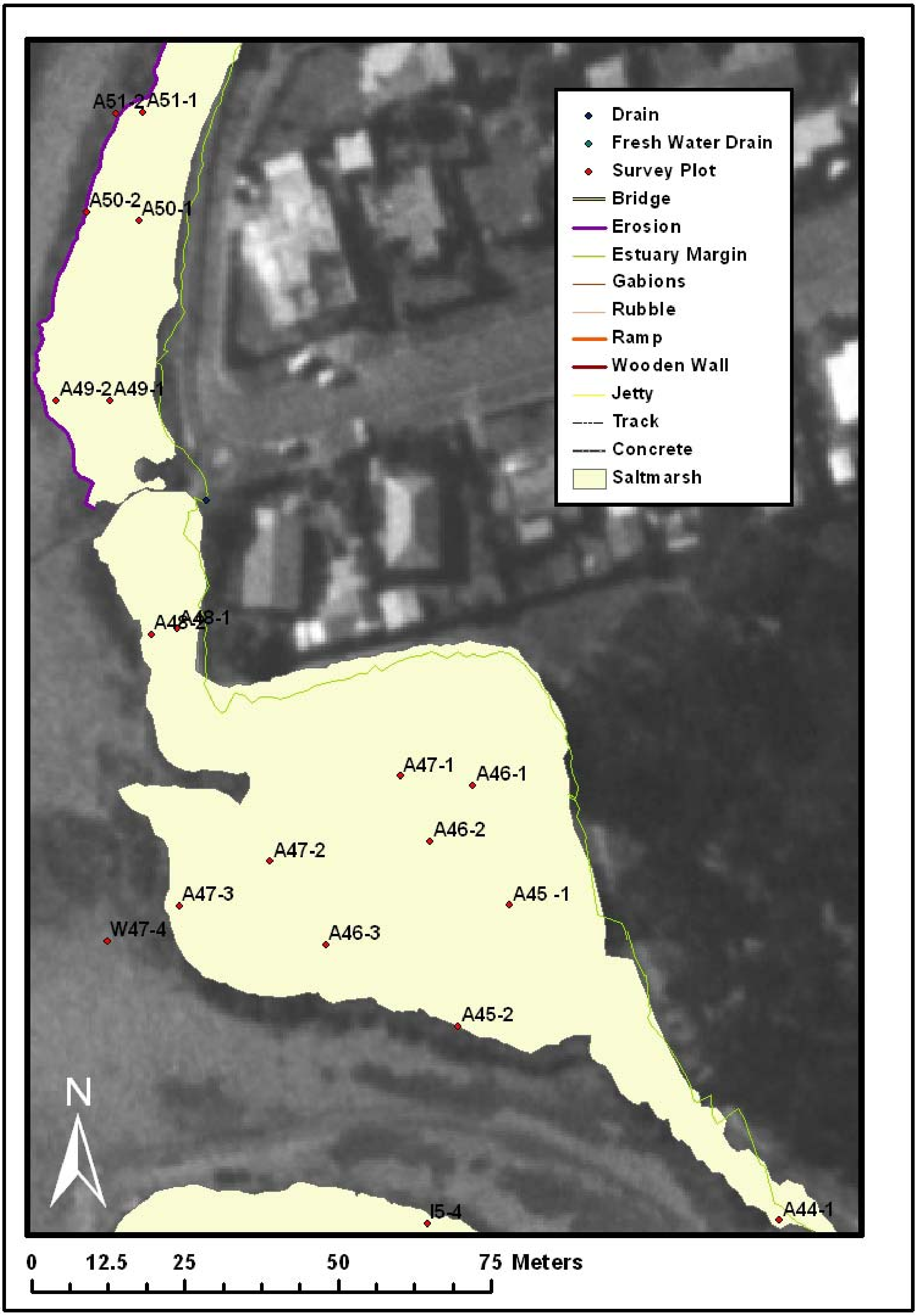

Figure 3.24 Salt marsh map of Avon River true left bank northern part of area 2

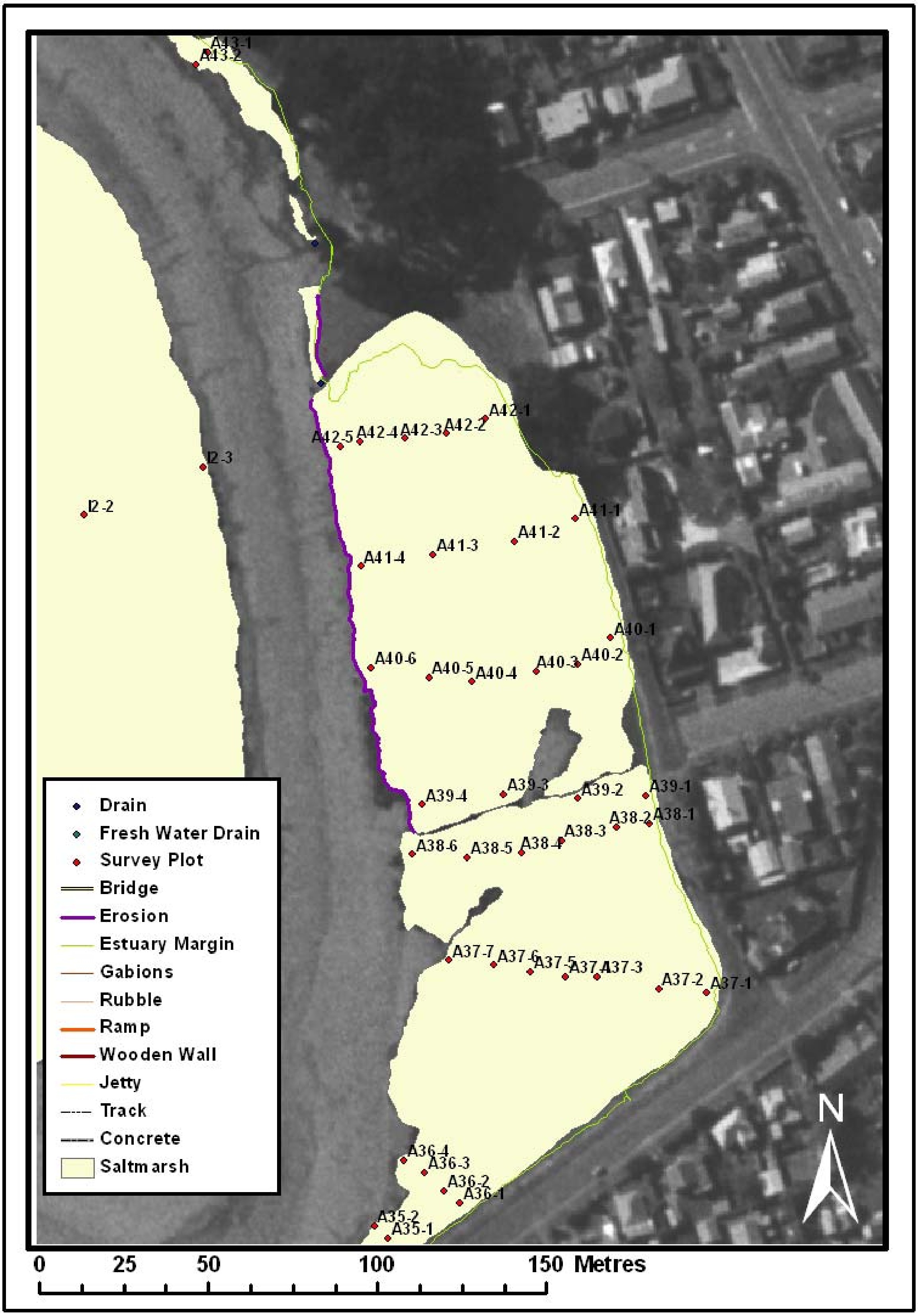

Figure 3.25 Salt marsh map of Avon River true left bank middle part of area 2

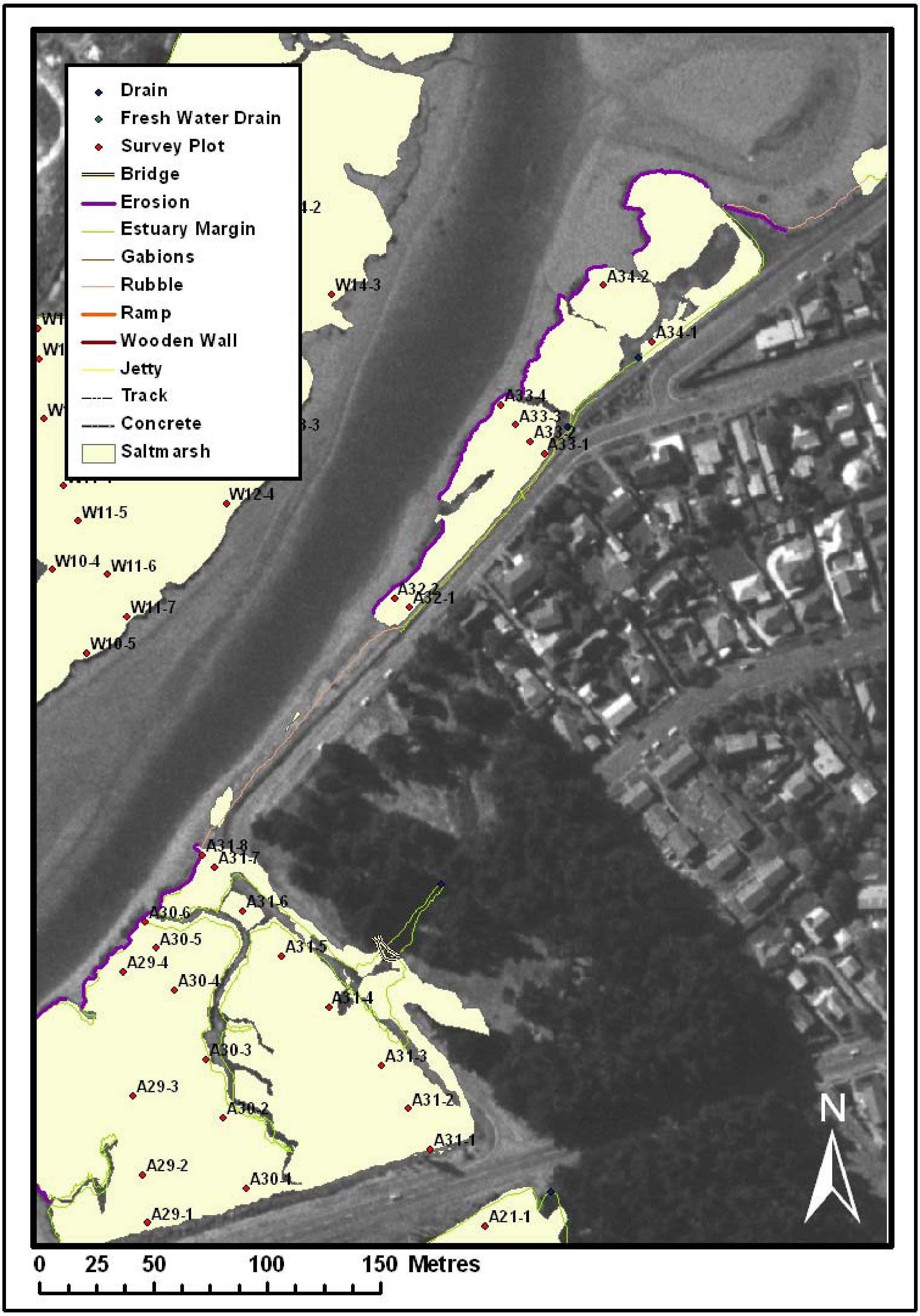

Figure 3.26 Salt marsh map of the Avon River true left bank southern part of area 2

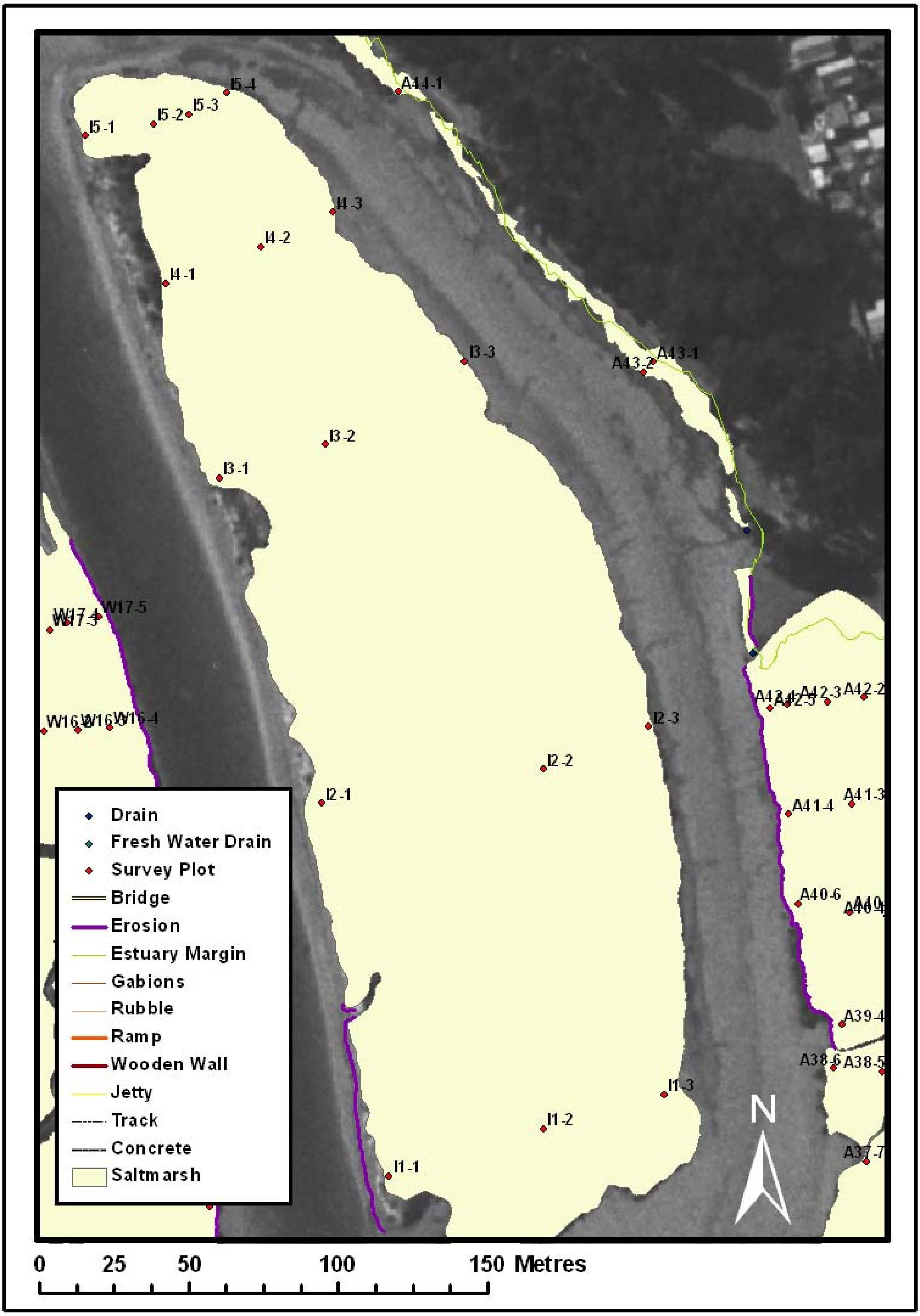

Figure 3.27 Salt marsh map of Naughty Boys' Island

Figure 3.28 Naughty Boys' Island study area 3

Naughty Boys' Island study area 3

This island contains an isolated area of salt marsh with Oioi Rushland (Type 1) being the dominant community type (Figures 3.27-3.28). This was also the case in the 1992 study. The oioi (*Apodasmia similis*) appears to be slowly displacing the Salt marsh Herbfield (Type 3) in this area, which is also present but only in part of the areas. The total extent of salt marsh in this study area is 39561 m^2.

Rat Island study area 4

Illustrated in Figures 3.29-3.31, this area only contains one vegetation community type, Oioi Rushland (Type 1), which has not changed since the 1992 study. The total extent of salt marsh present in the study area is 17409 m^2. This salt marsh appears to be stable, although oioi (*Apodasmia similis*) is slowly displacing the smaller plants.

Figure 3.29 Rat Island northern side study area 4

Figure 3.30 Rat Island southern study area 4

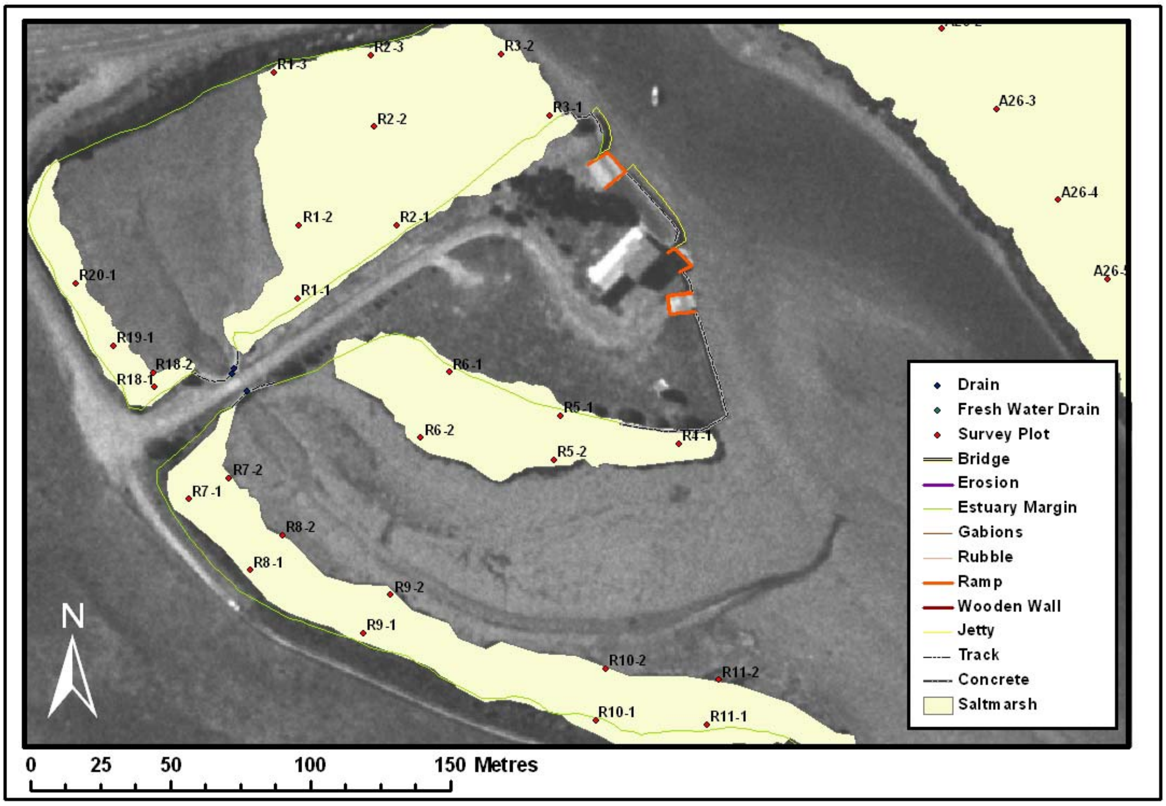

Figure 3.31 Salt marsh map of the Rat Island area 4

Below Bridge Street Bridge study area 5

Illustrated in Figures 3.32-3.34), this area contains a considerable 49063 m^2 of salt marsh. There is a range of vegetation types present (Types 1, 2, 3, 4, 5, 6), with Oioi Rushland (Type 1) and Three Square Sedgeland (Type 6) being the most dominant. In 1992 the diversity of vegetation types was greater (Types 1, 2, 3, 5, 6, 8, 9, 10, 11, 12). Salt marsh vegetation has disappeared from three sites in this area, A2-1, A6-5, and A6-6, which are located towards the bottom of the area near the jetty. These appear to have lost their salt marsh due to an increase in sedimentation which has increased the elevation of the sites.

Figure 3.32 Below Bridge Street Bridge in study area 5

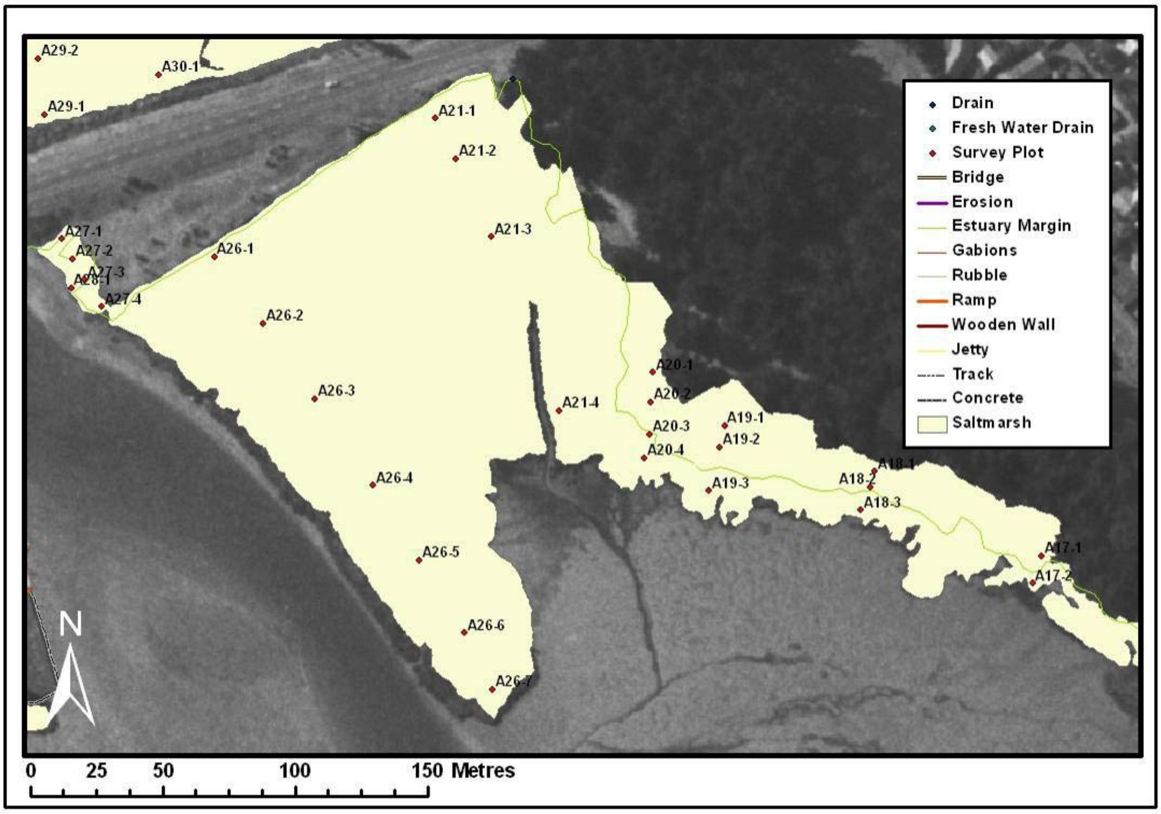

Figure 3.33 Salt marsh map below Bridge Street Bridge in the northern part of area 5

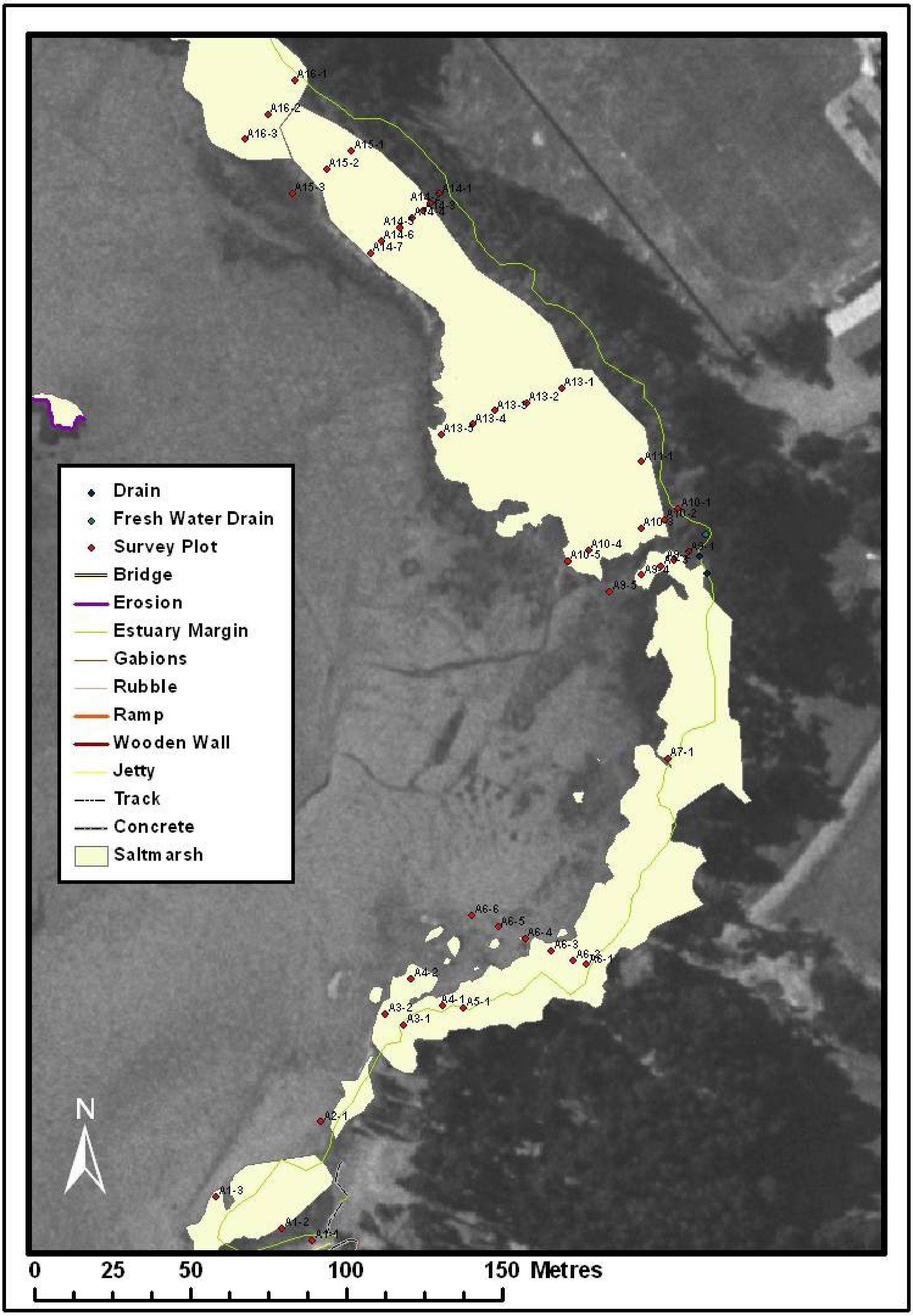

Figure 3.34 Salt marsh map below Bridge Street Bridge in the southern part of area 5

South Brighton near pines study area 6

The extent of salt marsh (22476 m^2) in this area is limited by an embankment, which shelters the area from the estuary (Figures 3.35-3.36). There are two drains which feed water into the area. The main drain was created in the 1980s when the salt marsh began to be invaded by pastoral weeds. This study shows the positive effect of creating this opening because the number of Tall Fescue and Coastal Ribbonwood sites (Type 5) decreased between 1992-2007 while Sea Rush Rushland (Type 2) was found to be the most dominant in vegetation type 2007 with the number of Salt marsh Herbfield (Type 3) sites considerably large as well (Table 3. 4). There is a variety of vegetation types present in this area (Types 2, 3, 4, 5).

Table 3.4 Transition Matrix of South Brighton study area 6

		2006-2007				
		1	2	3	4	5
1992-1993	1	0	4	1	0	0
	2	0	**13**	1	1	0
	3	0	7	**2**	2	0
	4	0	0	0	**1**	1
	5	0	3	6	0	**2**

Figure 3.35 South Brighton study area 6

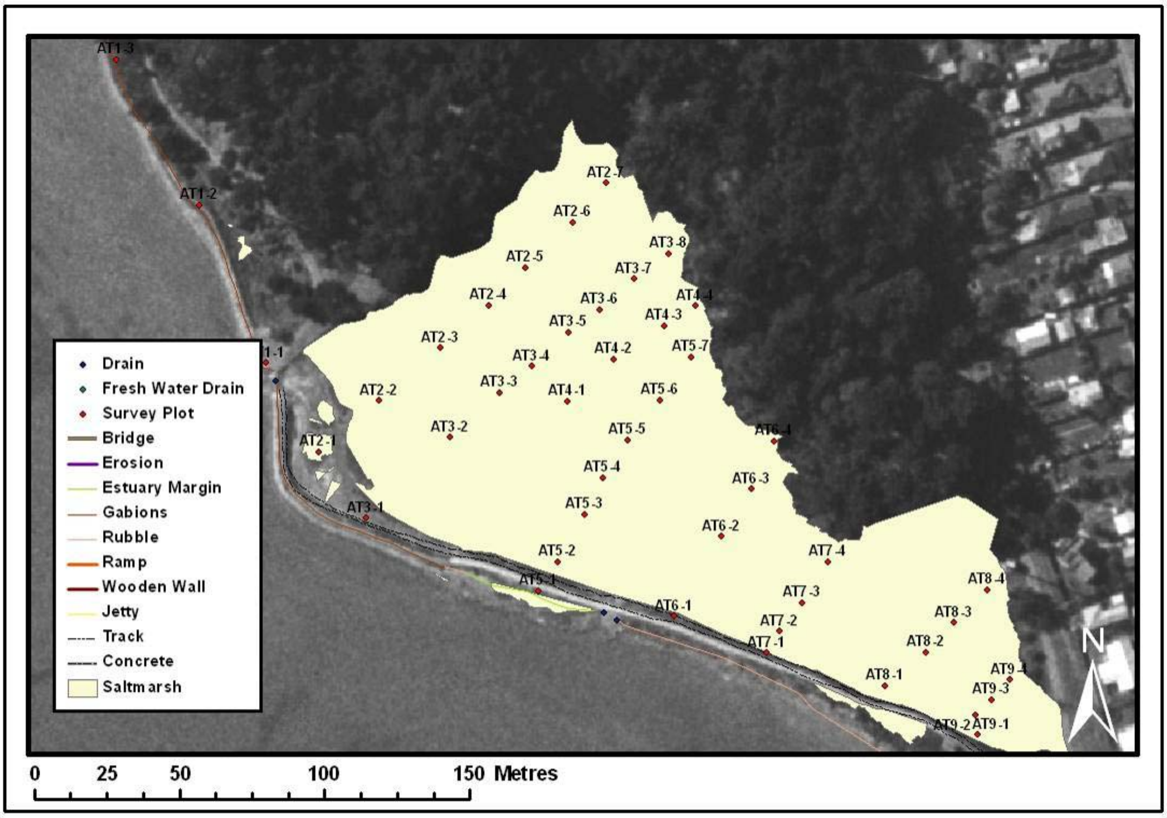

Figure 3.36 Salt marsh map of South Brighton area 6

Penguin Street study area 7

The small extent of salt marsh (7361 m^2) in this area is the closest salt marsh to the estuary mouth (Figures 3.37-3.38). There are two dominant vegetation community types present in the area, Sea Rush Rushland (Type 2) and Salt marsh Herbfield (Type 3). Very little change occurred in this area between 1992 and 2007 as the dominant community type has remained Sea Rush Rushland (Type 2).

Figure 3.37 Penguin Street study area 7

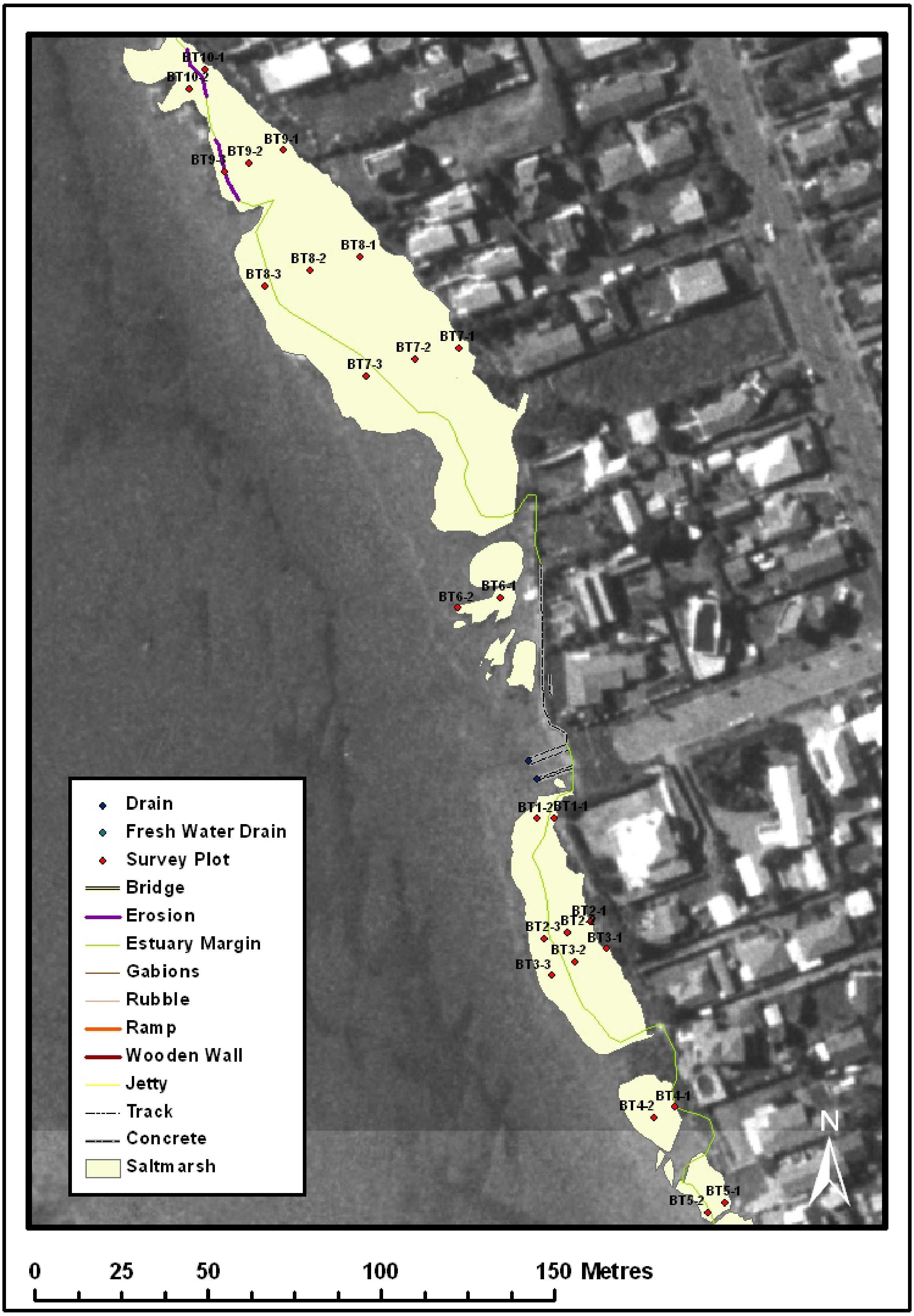

Figure 3.38 Salt marsh map for the Penguin Street area 7

Figure 3.39 Sandy Point study area 8

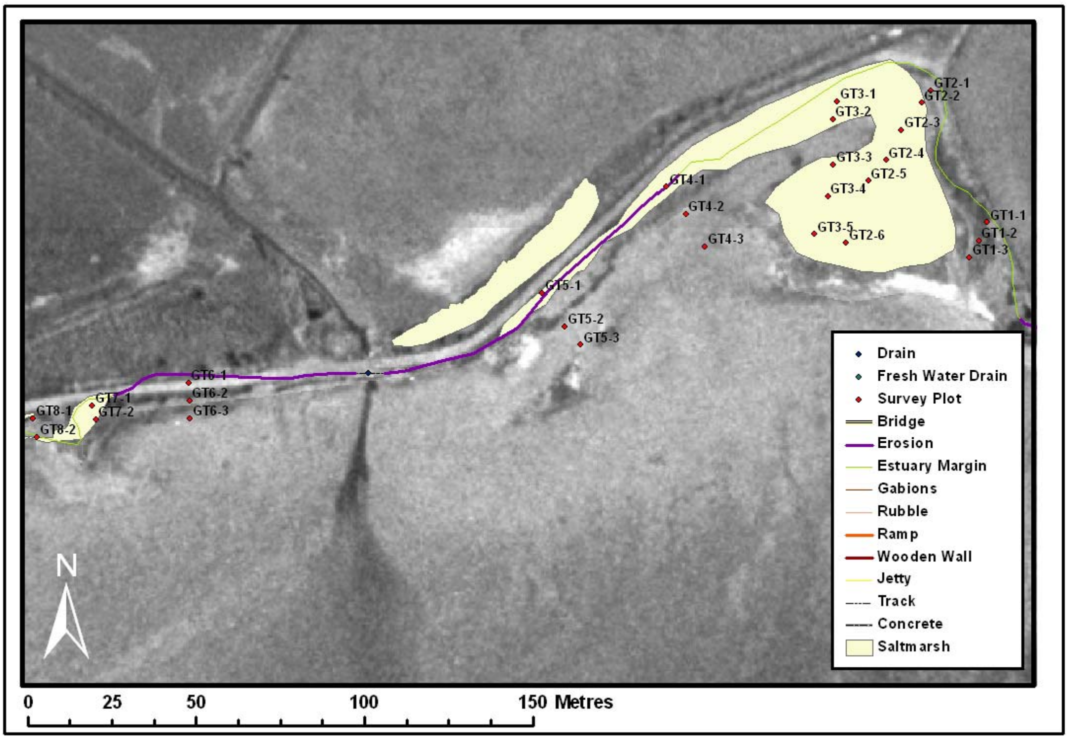

Figure 3.40 Salt marsh map for Sandy Point area 8

Sandy Point study area 8

Illustrated in Figures 3.39-3.40, this study area is the other location with the most 1992 survey sites which have had vegetation disappear in 2006. In eight of the 27 original 1992 sites the salt marsh vegetation has disappeared. These are GT4-1, GT4-2, GT4-3, GT5-2, GT5-3, GT6-1, GT6-2, GT6-3. This again may be due to sediment build-up causing the vegetation to dry out and die. Sea rush (*Juncus krausii*) is the main species affected by the sediment build-up. Due to the location of this study area it may act as a sediment trap. The extent of the salt marsh in this area is 3742 m^2, making it the smallest patch of salt marsh in the Avon-Heathcote Estuary. Sea Rush Rushland (Type 2) and Salt marsh Herbfield (Type 3) are the two dominant vegetation types in this area.

Charlesworth study area 9

The salt marsh in this area is also very diverse in relation to its size (16086 m^2) (Figures 3.41-3.42). Restoration work was taking place to the north of the area at the time fieldwork was conducted for this study. This was found to be the only study area where Coastal Ribbonwood Shrubland (Type 7) was present, Salt marsh Herbfield (Type 3) being the other vegetation type dominating here. Sea Rush Rushland (Type 2) was also found in some sites in this area. This area was in a poor state when it was surveyed in 1992, but due to the enlargement of the drain under the road connecting it to the estuarine tidal flow, the salt marsh has been able to re-established itself.

Figure 3.41 Charlesworth study area 9

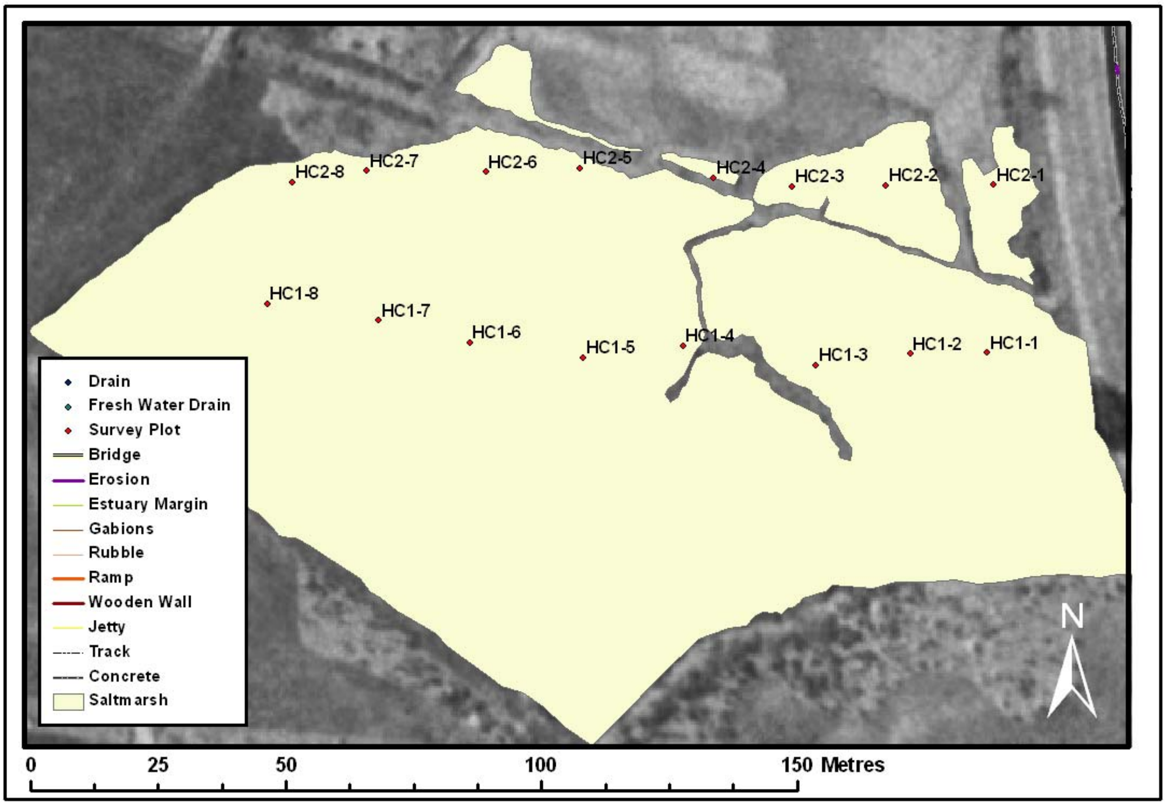

Figure 3.42 Salt marsh map for the Charlesworth area 9

Heathcote River Ferrymead Loop study area 10

The relatively large salt marsh (64287 m^2) in this area is one of the two locations with the most survey sites with vegetation that has disappeared (Figures 3.43-3.44). Again, this is likely the result of the high levels of sedimentation, in the Heathcote River. The survey sites which have lost vegetation, between 1992 and 2006, are FT1-1, FT1-6, FT2-1, FT2-7, FT3-1, FT6-1, FT7-1, FT8-1. Sea Rush Rushland (Type 2) is the dominant vegetation type found to be present in this location in 2007 and in 1992. There was also some Salt marsh Herbfield (Type 3) found. There was an increase in the proportion of Sea Rush Rushland (Type 2), but this has been offset by the loss in survey sites.

Figure 3.43 Heathcote Loop

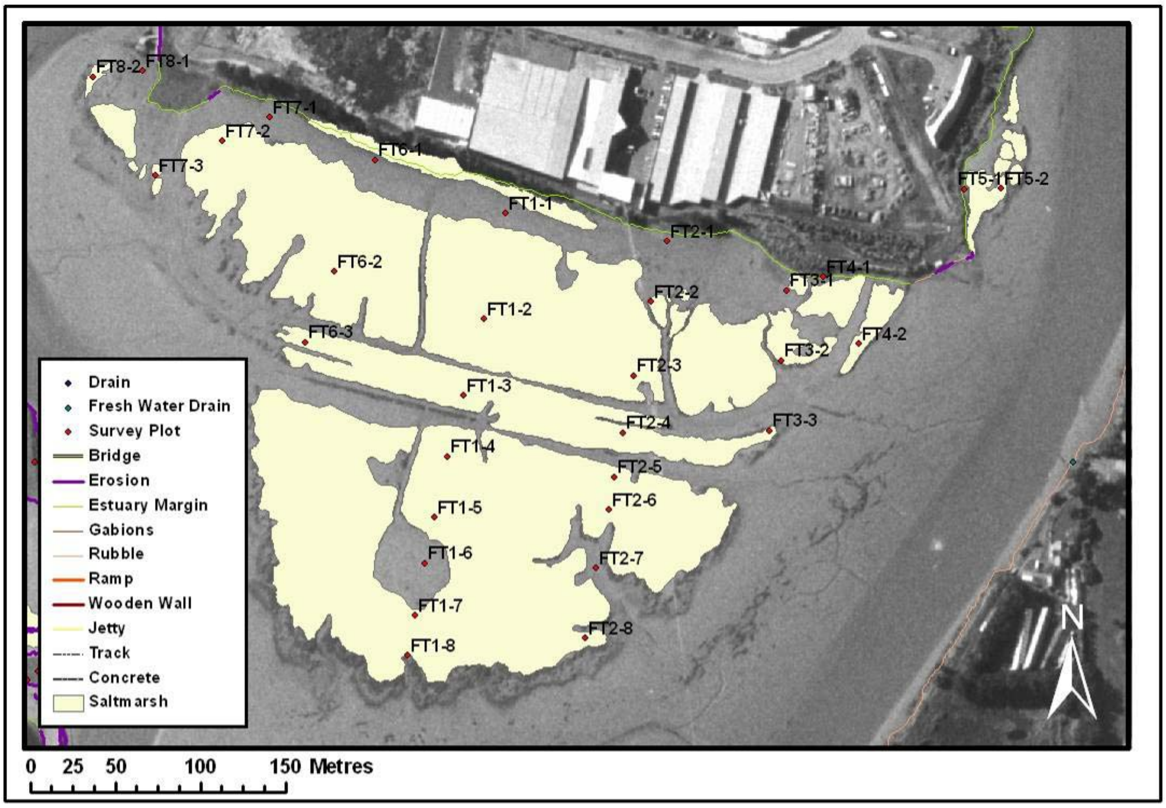

Figure 3.44 Salt marsh map of the Heathcote Loop area 10

Figure 3.45 Calders Green study area 11

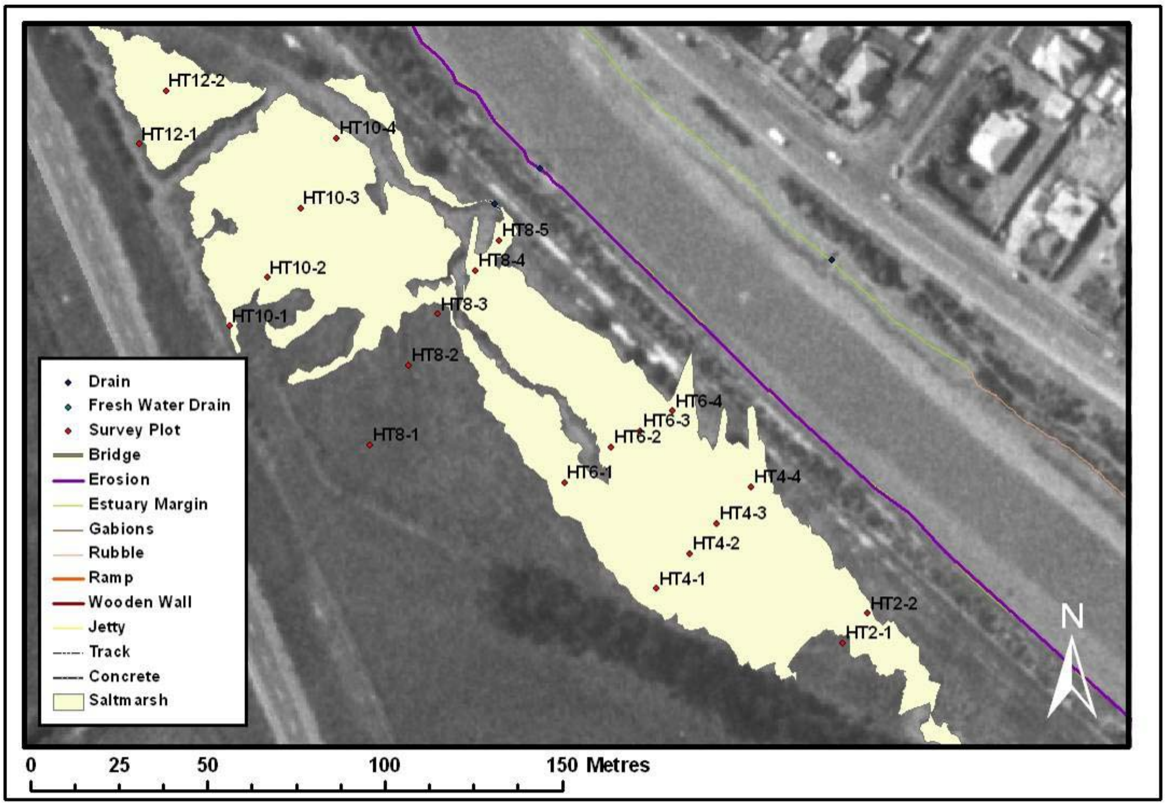

Figure 3.46 Salt marsh map for Calders Green area 11

Calders Green study area 11

Illustrated in Figures 3.45-3.46, the salt marsh in this area is very diverse for its size (10562 m^2) with three vegetation community types; Sea Rush Rushland (Type 2), Salt marsh Herbfield (Type 3) and Couch Grassland (Type 4). The vegetation has been lost at one survey site, HT12-1, possibly due to a decrease in the amount of water entering this marsh. This site is located furthest away from where the Heathcote waters enter the estuary, so this area may have been vulnerable to drying out due to its distant location from the water source. An interesting finding is that since 1992 couch has disappeared but this may be because the 2006-2007 survey sites were surveyed further into the salt marsh areas, rather than on the margins.

Heathcote River Devils Elbow study area 12

Sea Rush Rushland (Type 2) is the only vegetation type present in this area (Figures 3.47-3.48). This is the only site where no change has occurred over the 14 years between studies. The total extent of salt marsh is 9938 m^2.

Figure 3.47 Devils Elbow study area 12

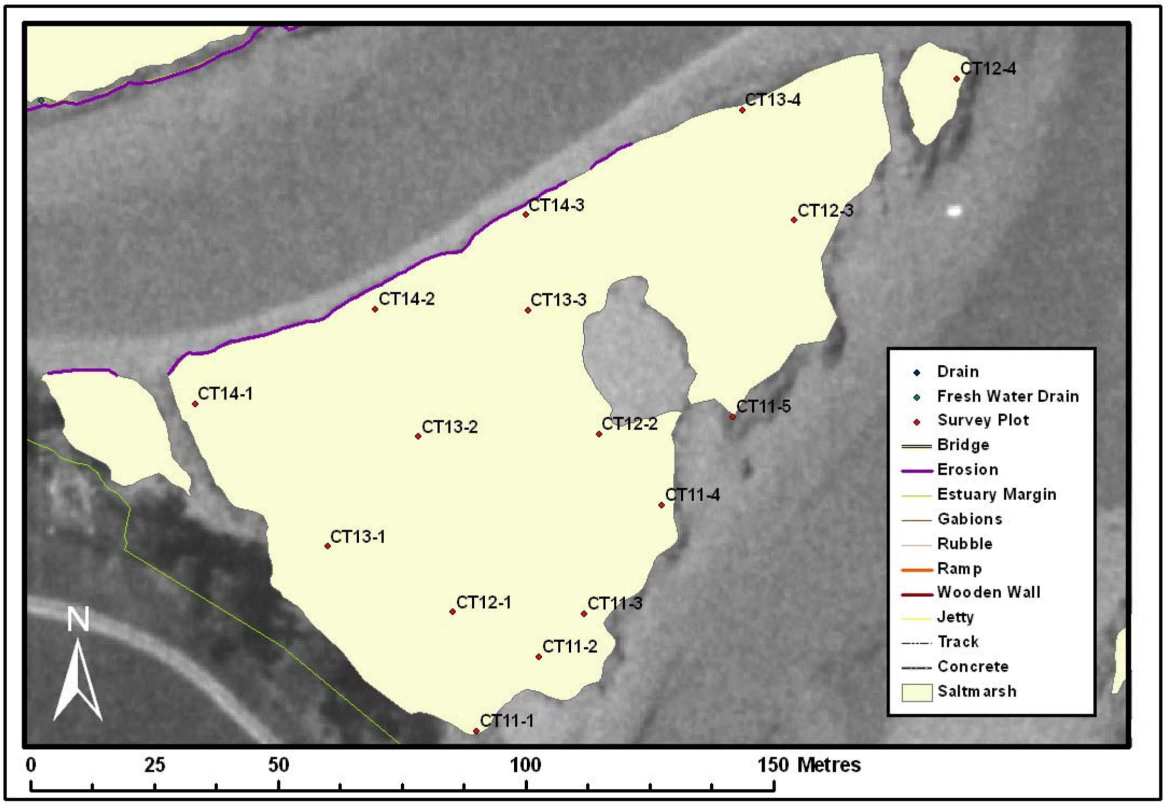

Figure 3.48 Salt marsh map of Devils Elbow area 12

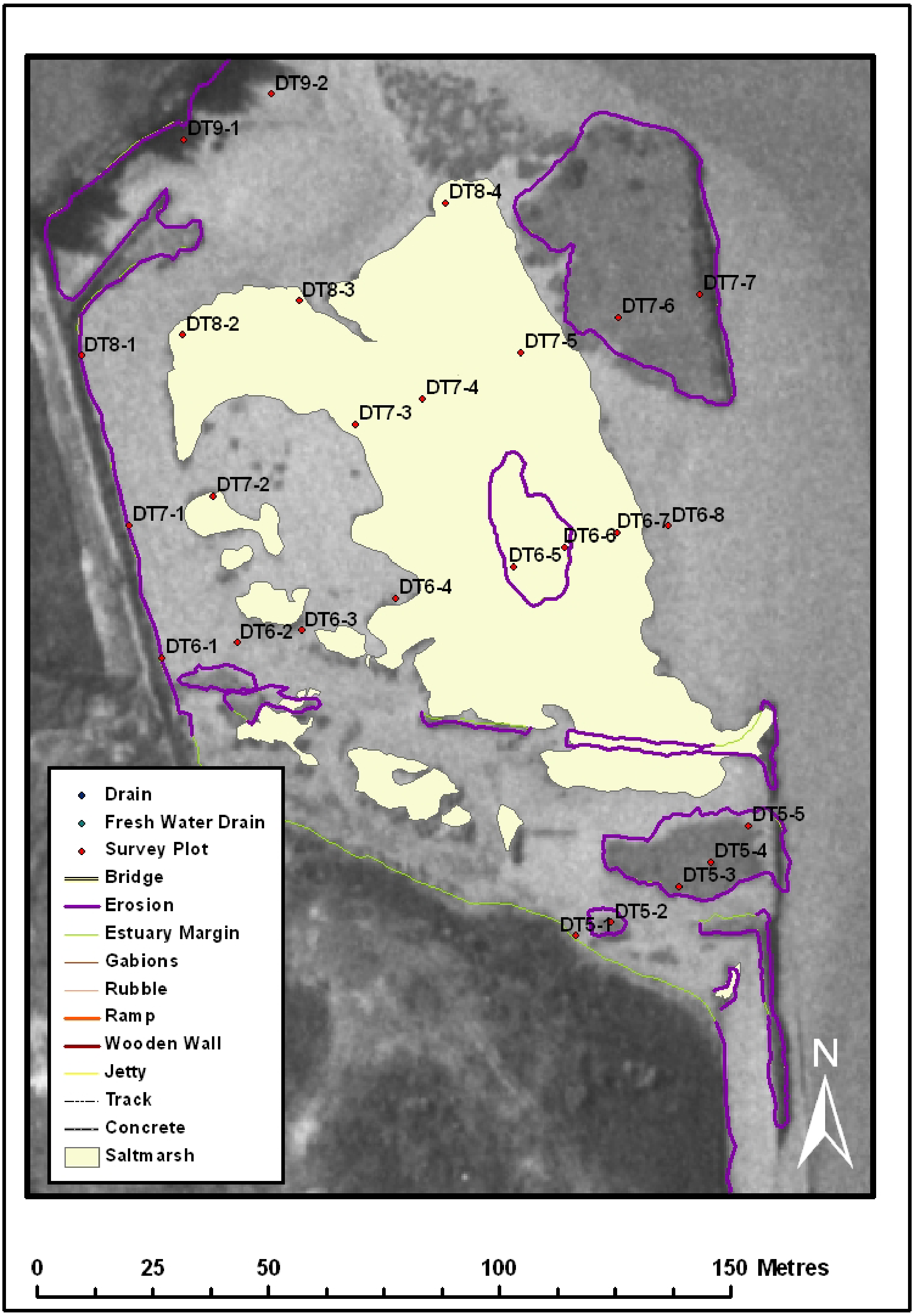

Figure 4.49 Salt marsh map of Heathcote above Ferrymead area 13

Figure 3.50 Heathcote above Ferrymead study area 13

Heathcote River Upstream of Ferrymead study area 13

The salt marsh in this area covers 7859 m^2 (Figure 3.49-3.50). The area varies a lot in elevation and some salt marsh vegetation has disappeared. Due to high levels of sedimentation in the Heathcote River (Hicks 1993) 5 sites no longer have any vegetation growing (DT6-1, DT6-2, DT6-8, DT8-1, DT9-1). The dominant community types have remained the same in this study area, Sea Rush Rushland (Type 2) and Salt marsh Herbfield (Type 3). Oioi Rushland (Type 1) is also found in one location.

Heathcote River Near Ferrymead study area 14

This area contains a small amount of salt marsh (5070 m^2) along the Heathcote River (Figures 4.51-4.52). The dominant vegetation type is Salt marsh Herbfield (Type 3) but Sea Rush Rushland (Type 2) also is present in three survey sites. An interesting finding in this area, which goes against the trend seen in the rest of the estuary, is the increase of Salt marsh Herbfield (Type 3). This increase however does not make up for what has been lost in the Avon River.

Figure 3.51 Heathcote River near Ferrymead study area 14

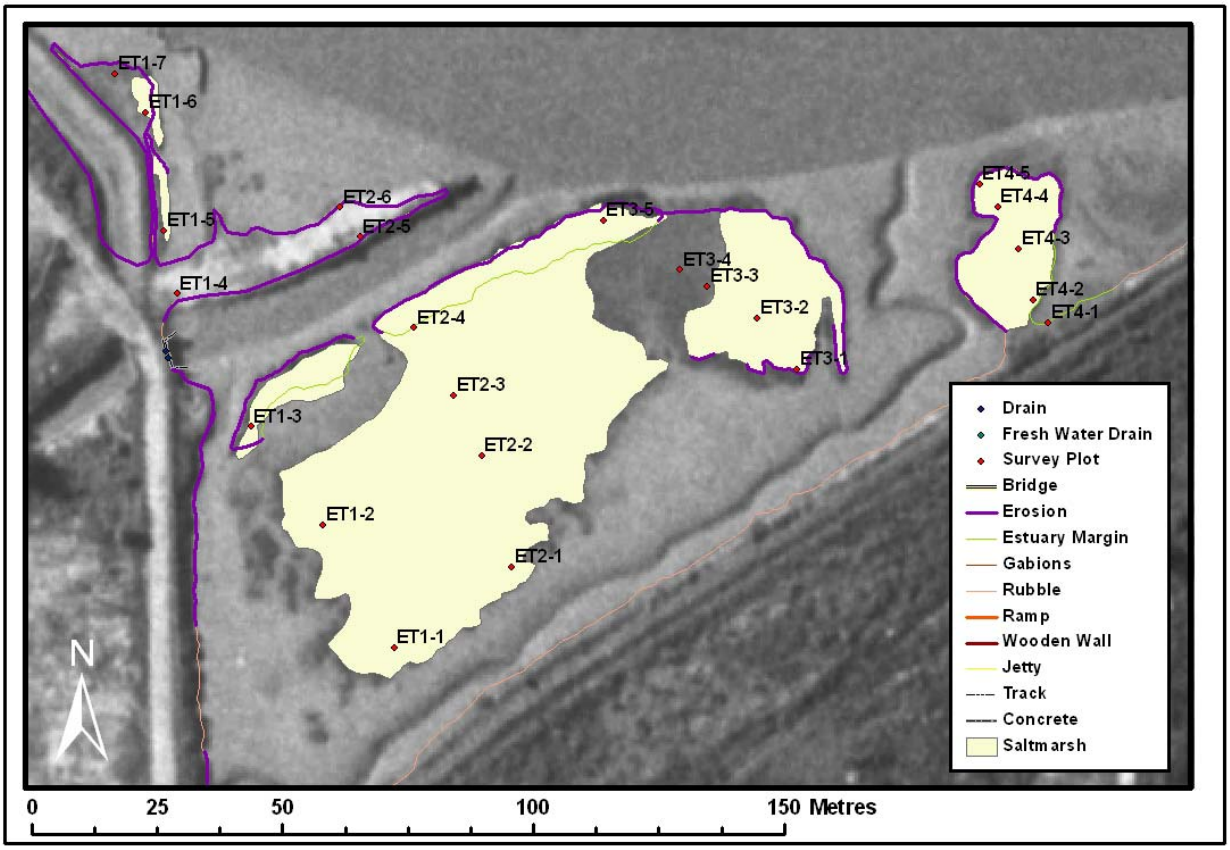

Figure 3.52 Salt marsh map of Heathcote above Ferrymead area 14

4.0 Discussion

During the twentieth century increasing human populations and coastal development have applied pressure to estuaries and the salt marshes that grow in them. Salt marshes around the world are under threat due to this pressure. Activities such as reclamation and draining of wetlands, and building around salt marsh margins have been major influences in salt marsh vegetation decline. To reduce the amount of salt marshes being lost they need to be monitored. This is to ensure that human impact is managed in a way to sustain the vegetation. Studies such as McCombs and Partridge (1992) and the present one are crucial for obtaining this information.

Within the Avon-Heathcote estuary, the areas of salt marsh surrounding the Avon River were found to be the most stable. This is due to the large amount of oioi (*Apodasmia similes*) and sea rush (*Juncus krausii*) present. Overall, Rushlands (Type 1 and Type 2) were found to form stable communities. However, this has often been at the cost of the small herbaceous plants, such as the native musk (*Mimulus repens*), which have nearly disappeared. This type of vegetation change has been most noticeable in the Avon River. As the sea rush (*Juncus krausii*), oioi (*Apodasmia similes*) and coastal ribbonwood (*Plagianthus divaricatus*) have become more established due to slight increases in sediment, small plants are smothered and die under the taller and thicker plants. Coastal ribbonwood (*Plagianthus divaricatus*) has increased at such a rate that it now has its own community type, Coastal Ribbonwood Shrubland (Type 7). The spread of this vegetation type has resulted in the loss of the smaller plants.

This research suggests that oioi (*Apodasmia similes*) is spreading due to increased sedimentation due to human impact. This raises important questions such as: should action be taken to stop this spread in order to save the herbaceous plants, or should the displacement process be allowed to continue. It would be virtually impossible to reverse the sediment accumulation that has occurred without affecting natural sediment process. It is important to note that native musk (*Mimulus repens*) is commonly found at Brooklands Lagoon and in Waihora Lake Ellesmere, but here too it may disappear due to the spread of rushlands as seen in the Avon-Heathcote Estuary.

High levels of sedimentation, especially in the Heathcote River and near Sandy Point may have caused some areas of sea rush vegetation to disappear. This increased sedimentation has resulted in the drying out of these sites due to increased elevation. This is most clearly seen in the Heathcote Loop and at Sandy Point, areas where the highest number of salt marsh sites have had vegetation disappear . The increase of sediment entering the estuary via the Heathcote River is due to high levels of housing development in the surrounding area (Figure 4.1). Although the impacts of this development activity on the estuary tend to be indirect, via sediment runoff, there are examples around the Avon-Heathcote Estuary where deliberate destruction by humans is also taking place (Figures 4.2). Humans have been both directly and indirectly responsible for a proportion of the change that has occurred since 1992.

As GPS was not used in the 1992 study it made finding certain study sites difficult. This may have some bearing on some of the extreme findings seen in Table 3.1. The use of GPS will allow future studies to be far more accurate.

Figure 4.1 Areas of development above the Heathcote River

Figure 4.2 Damage to the salt marshes by direct human impacts, including markings caused by motor bikes at Calders Green (left) and clearing for access to a house near Penguin Street (right)

This comparative study suggests that the estuary is infilling with fine sediments. This assumption is based on the observed spread of sea rush (*Juncus krausii*) and oioi (*Apodasmia similes*). Sea rush (*Juncus krausii*) prefers to occupy fine sediments, which keep salinity levels from fluctuating greatly (Partridge and Wilson 1989). Herbaceous plants are more likely to be able to out-compete sea rush (*Juncus krausii*) and dominate where coarse sediments occur, due to the higher salinities found in these areas. Oioi (*Apodasmia similes*) and coastal ribbonwood (*Plagianthus divaricatus*) are less salt tolerant than herbaceous species. As oioi (*Apodasmia similes*) and sea rush (*Juncus krausii*) are the species that have spread the most around the Avon-Heathcote Estuary, this suggests an increase in the amounts of fine sediments being deposited on the salt marsh. This has resulted in the numbers of salt-tolerant species decreasing as they are displaced by sea rush (*Juncus krausii*) in the Avon-Heathcote Estuary.

5.0 Conclusions and Future Research

This comparative study has found that since McCombs and Partridge (1992) there has been a loss of five percent of the original salt marsh sites. There may have been new sites created, but due to the comparative nature of this study they were not studied. This study calculated the total extent of salt marsh vegetation in the study areas to be 372163 m^2. This figure can be used in future studies to determine changes in salt marsh coverage.

The Avon River salt marsh areas were found to be the most stable, with the least change occurring in areas where this vegetation. The majority of vegetation lost was sea rush (*Juncus krausii*), due to high levels of sedimentation in the Heathcote loop, and, likewise, salt marsh herb field at Sandy Point. Although sea rush (*Juncus krausii*) has disappeared with the loss of some study sites, it has experienced an overall increase in extent of 6%. Oioi (*Apodasmia similes*) too has increased by 3%. While it is good to see these increases, unfortunately it has been at the expense of herb field plants numbers, which have decreased. The common trend found was that smaller herbaceous plants have decreased their coverage due to the increase in oioi (*Apodasmia similes*), sea rush (*Juncus krausii*) and coastal ribbonwood (*Plagianthus divaricatus*) densities.

Change from salt tolerant plants to rushlands suggests that the Avon-Heathcote Estuary is infilling with fine sediments, and that this is occurring at the expense of the smaller herbaceous plants. The issue arises as to whether or not to anything should be done about this change.

This report details the first part of an ongoing research project on the Avon-Heathcote salt marshes. The second part will form an honours dissertation by Jupp (2007). When completing the vegetation surveys, sediment samples were taken at various locations along each transect. In the honours dissertation, these samples will be analysed for sediment size, salinity and nitrate levels to build on the sediment ideas formed in this report. Data on another important physical variable, elevation, will be obtained from the GPS data. The sediment and elevation variables will then be correlated with the different vegetation types to determine which species grow well under which physical conditions. A framework will be created to help restoration workers understand where to plant the different salt marsh species to ensure the restoration is successful.

To ensure the Avon-Heathcote Estuary salt marsh vegetation is managed in a sustainable manner continued monitoring needs to take place. It would be recommended that this study is repeated in another 8 to 10 years. The vegetation surveys and mapping of the estuary margins should be carried out. To ensure sustainable management and to reduce human impact of the Avon-Heathcote Estuary a management plan should be created by the council authority stating what activities can and cannot take place in the estuary and its margins. If these recommendations take place it will help ensure that the salt marshes are present for future generations.

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Appendix 1

Table A1. Codes used for survey sites in 1992 and 2006

Study Site	**Survey Site Codes**	
	1992	**2006**
Avon River true right bank	TW1-1 TW2-1 – TW2-5 TW3-1 TW4-1 TW5-1 – TW5-2 TW6-1 – TW6-4 TW7-1 – TW7-3 TW8-1 – TW8-5 TW9-1 – TW9-5 TW10-1 – TW10-5 TW11-1 – TW11-7 TW12-1 – TW12-4 TW13-1 – TW13-3 TW14-1 – TW14-3 TW15-1 – TW15-6 TW16-1 – TW16-4 TW17-1 – TW17-5	W1-1 W2-1 – W2-5 W3-1 W4-1 W5-1 – W5-2 W6-1 – W6-4 W7-1 – W7-3 W8-1 – W8-5 W9-1 – W9-5 W10-1 – W10-5 W11-1 – W11-7 W12-1 – W12-4 W13-1 – W13-3 W14-1 – W14-3 W15-1 – W15-6 W16-1 – W16-4 W17-1 – W17-5
Avon River true left bank	A29-1 – A29-4 A30-1 – A30-6 A31-1 – A31-8 A32-1 – A32-2 A33-1 – A33-4 A34-1 – A34-2 A35-1 – A35-2 A36-1 – A36-4 A37-1 – A37-7 A38-1 – A38-6 A39-1 – A39-4 A40-1 – A40-6 A41-1 – A41-4 A42-1 – A42-5 A43-1 – A43-2 A44-1 A45-1 – A45-2 A46-1 – A46-3 A47-1 – A47-4 A48-1 – A48-2 A49-1 – A49-2 A50-1 – A50-2 A51-1 – A51-2	A29-1 – A29-4 A30-1 – A30-6 A31-1 – A31-8 A32-1 – A32-2 A33-1 – A33-4 A34-1 – A34-2 A35-1 – A35-2 A36-1 – A36-4 A37-1 – A37-7 A38-1 – A38-6 A39-1 – A39-4 A40-1 – A40-6 A41-1 – A41-4 A42-1 – A42-5 A43-1 – A43-2 A44-1 A45-1 – A45-2 A46-1 – A46-3 A47-1 – A47-4 A48-1 – A48-2 A49-1 – A49-2 A50-1 – A50-2 A51-1 – A51-2
Naughty Boy's Island	I1-1 – I1-3 I2-1 – I2-3 I3-1 – I3-3 I4-1 – I4-3 I5-1 – I5-4	I1-1 – I1-3 I2-1 – I2-3 I3-1 – I3-3 I4-1 – I4-3 I5-1 – I5-4
Rat Island	R1-1 – R1-3 R2-1 – R2-3 R3-1 – R3-2 R4-1 R5-1 – R5-2 R6-1 – R6-2	R1-1 – R1-3 R2-1 – R2-3 R3-1 – R3-2 R4-1 R5-1 – R5-2 R6-1 – R6-2

	R7-1 – R7-2 R8-1 – R8-2 R9-1 – R9-2 R10-1 – R10-2 R11-1 – R11-2 R12-1 – R12-2 R13-1 R14-1 R15-1 R16-1 – R16-2 R17-1 – R17-3 R18-1 – R18-2 R19-1 – R19-1 R20-1	R7-1 – R7-2 R8-1 – R8-2 R9-1 – R9-2 R10-1 – R10-2 R11-1 – R11-2 Did not survey “ “ “ “ “ “ “ “ “ “ “ “ “ “ “ R18-1 – R18-2 R19-1 – R19-1 R20-1
Below Bridge Street Bridge	A1-1 – A1-3 A2-1 A3-1 – A3-2 A4-1 – A4-2 A5-1 A6-1 – A6-6 A7-1 A8-1 – A8-4 A9-1 – A9-5 A10-1 – A10-5 A11-1 A12-1 – A12-8 A13-1 – A13-5 A14-1 – A14-7 A15-1 – A15-3 A16-1 – A16-3 A17-1 – A17-2 A18-1 – A18-3 A19-1 – A19-3 A20-1 – A20-4 A21-1 – A21-4 A22-1 – A22-5 A23-1 – A23-5 A24-1 – A24-2 A25-1 – A25-2 A26-1 – A26-7 A27-1 – A27-4 A28-1	A1-1-3 A2-1 A3-1 – A3-2 A4-1 – A4-2 A5-1 A6-1 – A6-6 A7-1 Did not survey, transect close to previous A9-1 – A9-5 A10-1 – A10-5 A11-1 Did not survey, transect close to previous A13-1 – A13-5 A14-1 – A14-7 A15-1 – A15-3 A16-1 – A16-3 A17-1 – A17-2 A18-1 – A18-3 A19-1 – A19-3 A20-1 – A20-4 A21-1 – A21-4 Did not survey “ “ “ “ “ “ “ “ “
South Brighton near pines	T1-1 – T1-3 T2-1 – T2-7 T3-1 – T3-8 T4-1 – T4-4 T5-1 – T5-7 T6-1 – T6-4 T7-1 – T7-4 T8-1 – T8-4 T9-1 – T9-4	AT1-1 – AT1-3 AT2-1 – AT2-7 AT3-1 – AT3-8 AT4-1 – AT4-4 AT5-1 – AT5-7 AT6-1 – AT6-4 AT7-1 – AT7-4 AT8-1 – AT8-4 AT9-1 – AT9-4
Penguin St Reserve	T1-1 – T1-2 T2-1 – T2-3 T3-1 – T3-3 T4-1 – T4-2 T5-1 – T5-2 T6-1 – T6-2 T7-1 – T7-3 T8-1 – T8-3 T9-1 – T9-3	BT1-1 – BT1-2 BT2-1 – BT2-3 BT3-1 – BT3-3 BT4-1 – BT4-2 BT5-1 – BT5-2 BT6-1 – BT6-2 BT7-1 – BT7-3 BT8-1 – BT8-3 BT9-1 – BT9-3

	T10-1 – T10-2	BT10-1 – BT10-2
Sandy Point	T1-1 – T1-3 T2-1 – T2-6 T3-1 – T3-5 T4-1 – T4-3 T5-1 – T5-3 T6-1 – T6-3 T7-1 – T7-2 T8-1 – T8-2	GT1-1 – GT1-3 GT2-1 – GT2-6 GT3-1 – GT3-5 GT4-1 – GT4-3 GT5-1 – GT5-3 GT6-1 – GT6-3 GT7-1 – GT7-2 GT8-1 – GT8-2
Charlesworth	C1-1 – C1-8 C2-1 – C2-8	HC1-1 – HC1-8 HC2-1 – HC2-8
Heathcote River (Ferrymead Loop)	T1-1 – T1-8 T2-1 – T2-8 T3-1 – T3-3 T4-1 – T4-2 T5-1 – T5-2 T6-1 – T6-3 T7-1 – T7-3 T8-1 – T8-2	FT1-1 – FT1-8 FT2-1 – FT2-8 FT3-1 – FT3-3 FT4-1 – FT4-2 FT5-1 – FT5-2 FT6-1 – FT6-3 FT7-1 – FT7-3 FT8-1 – FT8-2
Calders Green	T1-1 – T1-2 T2-1 –T2-2 T3-1 – T3-2 T4-1 – T4-4 T5-1 – T5-4 T6-1 – T6-4 T7-1 – T7-4 T8-1 – T8-5 T9-1 – T9-5 T10-1 – T10-4 T11-1 – T11-3 T12-1 – T12-3 T13-1 –T13-3	Did not survey as transect is close to previous HT2-1 –HT2-2 Did not survey as transect is close to previous HT4-1 – HT4-4 Did not survey as transect is close to previous HT6-1 – HT6-4 Did not survey as transect is close to previous HT8-1 – HT8-5 Did not survey as transect is close to previous HT10-1 – HT10-4 Did not survey as transect is close to previous HT12-1 – HT12-3 Did not survey as transect is close to previous
Heathcote River (Devils Elbow)	T11-1 – T11-5 T12-1 – T12-4 T13-1 – T13-4 T14-1 – T14-3	CT11-1 – CT11-5 CT12-1 – CT12-4 CT13-1 – CT13-4 CT14-1 – CT14-3
Heathcote River (Upstream of Ferrymead)	T5-1 – T5-5 T6-1 – T6-8 T7-1 – T7-7 T8-1 – T8-4 T9-1 – T9-2 T10-1	DT5-1 – DT5-5 DT6-1 – DT6-8 DT7-1 – DT7-7 DT8-1 – DT8-4 DT9-1 – DT9-2 Did not survey as could not find location
Heathcote River (Near Ferrymead, true right of river)	T1-1 – T1-7 T2-1 – T2-6 T3-1 – T3-5 T4-1 – T4-5	ET1-1 – ET1-7 ET2-1 – ET2-6 ET3-1 – ET3-5 ET4-1 – ET4-5
Cockayne Reserve	T1-1 – T1-5 T2-1 – T2-5 T3-1 – T3-5 T4-1 – T4-5 T5-1 – T5-4 T6-1 – T6-5 T7-1 – T7-3	Did not survey because this area has been used as a restoration project, therefore would not be surveying natural changes.

Appendix 2

Table A2. New Zealand Map Grid coordinates for each survey site

Site Code	Northing	Easting
Calders Green		
HT2-1	5738934.724	2485323.747
HT2-2	5738943.007	2485330.915
HT4-1	5738949.965	2485271.191
HT4-2	5738959.804	2485280.609
HT4-3	5738968.281	2485288.345
HT4-4	5738978.619	2485297.985
HT6-1	5738979.892	2485245.291
HT6-2	5738989.986	2485258.602
HT6-3	5738994.396	2485266.848
HT6-4	5739000.086	2485275.809
HT8-1	5738990.444	2485190.472
HT8-2	5739013.112	2485201.471
HT8-3	5739027.508	2485209.587
HT8-4	2485226.904	2485220.164
HT8-5	5739048.316	2485226.904
HT10-1	5739024.084	2485150.901
HT10-2	5739037.803	2485161.508
HT10-3	5739057.321	2485170.858
HT10-4	5739077.094	2485181.158
HT12-1	5739099.67	2485069.53
HT12-2	5739090.501	2485132.898
HT12-3	5739114.05	2485133.127
Rat Island		
R1-1	5742305.351	2487604.877
R1-2	5742331.53	2487605.359
R1-3	5742386.089	2487596.198
R2-1	5742331.563	2487639.988
R2-2	5742366.66	2487631.908
R2-3	5742392.271	2487631.07
R3-1	5742370.753	2487694.821
R3-2	5742392.527	2487677.455
R4-1	5742253.384	2487740.899
R5-1	5742263.462	2487698.72
R5-2	5742247.677	2487696.341
R6-1	5742278.981	2487659.063
R6-2	5742255.431	2487648.82
R7-1	5742233.557	2487565.933
R7-2	5742241.055	2487580.352
R8-1	5742208.153	2487587.839
R8-2	5742220.695	2487599.263
R9-1	5742185.665	2487628.068
R9-2	5742199.276	2487638.048
R10-1	5742154.494	2487711.18
R10-2	5742172.954	2487714.94
R11-1	5742153.003	2487750.973
R11-2	5742168.981	2487755.233
R18-1	5742273.63	2487553.439
R18-2	5742278.676	2487553.048
R19-1	5742288.371	2487538.972
R20-1	5742310.624	2487525.505
Sandy Point		
GT1-1	5740001.776	2486729.544

GT1-2	5739996.373	2486727.012
GT1-3	5739991.514	2486724.231
GT2-1	5740041.024	2486712.855
GT2-2	5740037.242	2486709.956
GT2-3	5740029.213	2486704.025
GT2-4	5740020.279	2486699.454
GT2-5	5740014.171	2486694.133
GT2-6	5739995.726	2486687.55
GT3-1	5740037.798	2486685.009
GT3-2	5740032.406	2486683.644
GT3-3	5740018.928	2486683.774
GT3-4	5740009.635	2486682.209
GT3-5	5739998.306	2486678.235
GT4-1	5740012.361	2486634.328
GT4-2	5740004.244	2486639.925
GT4-3	5739994.78	2486645.52
GT5-1	5739980.81	2486597.432
GT5-2	5739970.866	2486604.117
GT5-3	5739964.96	2486608.91
GT6-1	5739954.207	2486492.29
GT6-2	5739948.902	2486492.626
GT6-3	5739938.67	2486478.91
GT7-1	5739947.377	2486463.716
GT7-2	5739943.405	2486464.793
GT8-1	5739943.746	2486446.213
GT8-2	5739938.004	2486447.259
Penguin St Reserve		
BT1-1	5740090.599	2489328.314
BT1-2	5740090.57	2489323.384
BT2-1	5740060.651	2489339.211
BT2-2	5740057.498	2489332.215
BT2-3	5740055.891	2489325.572
BT3-1	5740052.844	2489343.637
BT3-2	5740049.213	2489334.589
BT3-3	5740045.077	2489327.857
BT4-1	5740007.073	2489363.29
BT4-2	5740004.041	2489357.187
BT5-1	5739979.554	2489377.778
BT5-2	5739976.732	2489372.856
BT6-1	5740154.37	2489312.91
BT6-2	5740151.424	2489300.525
BT7-1	5740226.523	2489301.011
BT7-2	5740223.455	2489288.407
BT7-3	5740218.584	2489274.265
BT8-1	5740253.012	2489272.64
BT8-2	5740249.063	2489257.946
BT8-3	5740244.44	2489245.211
BT9-1	5740283.755	2489250.244
BT9-2	5740280.223	2489240.48
BT9-3	5740277.541	2489233.32
BT10-1	5740307.266	2489227.688
BT10-2	5740301.675	2489223.221
Heathcote Above Ferrymead		
HT5-1	5738262.874	2485836.215
HT5-2	5738265.695	2485843.668
HT5-3	5738273.513	2485858.522
HT5-4	5738278.811	2485865.284
HT5-5	5738286.573	2485873.433

HT6-1	5738322.958	2485746.645
HT6-2	5738326.29	2485762.861
HT6-3	5738328.945	2485776.785
HT6-4	5738335.829	2485797.085
HT6-5	5738342.697	2485822.821
HT6-6	5738346.886	2485833.649
HT6-7	5738350.142	2485845.208
HT6-8	5738351.517	2485856.101
HT7-1	5738351.649	2485739.655
HT7-2	5738358.066	2485757.809
HT7-3	5738373.603	2485788.553
HT7-4	5738379.103	2485803.073
HT7-5	5738389.006	2485824.387
HT7-6	5738396.633	2485845.456
HT7-7	5738401.677	2485862.902
HT8-1	5738388.419	2485729.151
HT8-2	5738392.857	2485751.026
HT8-3	5738400.224	2485776.268
HT8-4	5738421.435	2485807.972
HT9-1	5738435.104	2485751.488
HT9-2	5738444.972	2485770.43
Heathcote Near Ferrymead		
ET1-1	5737974.303	2486005.782
ET1-2	5737998.743	2485991.635
ET1-3	5738018.308	2485977.233
ET1-4	5738044.825	2485962.507
ET1-5	5738057.372	2485959.96
ET1-6	5738080.984	2485956.284
ET1-7	5738088.644	2485950.195
ET2-1	5737990.346	2486029.258
ET2-2	5738012.59	2486023.292
ET2-3	5738024.519	2486017.676
ET2-4	5738038.033	2486009.821
ET2-5	5738056.16	2485998.992
ET2-6	5738062.075	2485995.066
ET3-1	5738029.799	2486086.173
ET3-2	5738039.954	2486078.183
ET3-3	5738046.363	2486068.275
ET3-4	5738049.588	2486062.82
ET3-5	5738059.418	2486047.519
ET4-1	5738039.105	2486136.199
ET4-2	5738043.624	2486133.158
ET4-3	5738053.831	2486130.383
ET4-4	5738062.241	2486126.214
ET4-5	5738066.669	2486122.5
Pines		
AT1-1	5741172.472	2488539
AT1-2	5741226.677	2488516.26
AT1-3	5741276.8	2488487.783
AT2-1	5741142.033	2488557.109
AT2-2	5741159.498	2488577.831
AT2-3	5741177.627	2488599.214
AT2-4	5741192.203	2488615.63
AT2-5	5741205.322	2488628.171
AT2-6	5741220.86	2488644.534
AT2-7	5741234.267	2488656.201
AT3-1	5741119.185	2488573.596
AT3-2	5741146.949	2488602.559

AT3-3	5741162.276	2488619.334
AT3-4	5741171.415	2488630.482
AT3-5	5741182.928	2488643.231
AT3-6	5741190.935	2488654.021
AT3-7	5741201.384	2488665.537
AT3-8	5741209.995	2488677.684
AT4-1	5741165.828	2488639.405
AT4-2	5741182.591	2488650.987
AT4-3	5741198.972	2488665.252
AT4-4	5741209.615	2488674.153
AT5-1	5741093.54	2488632.46
AT5-2	5741104.22	2488639.276
AT5-3	5741120.377	2488648.661
AT5-4	5741133.064	2488654.784
AT5-5	5741145.903	2488663.593
AT5-6	5741159.816	2488674.503
AT5-7	5741174.544	2488685.433
AT6-1	5741085.5	2488679.36
AT6-2	5741112.838	2488695.794
AT6-3	5741129.14	2488706.181
AT6-4	5741145.635	2488713.745
AT7-1	5741072.889	2488711.225
AT7-2	5741080.251	2488715.497
AT7-3	5741090.208	2488723.302
AT7-4	5741104.25	2488732.327
AT8-1	5741061.687	2488751.997
AT8-2	5741073.187	2488765.917
AT8-3	5741083.225	2488775.797
AT8-4	5741094.514	2488787.026
AT9-1	5741044.753	2488783.82
AT9-2	5741051.639	2488782.917
AT9-3	5741056.911	2488788.475
AT9-4	5741063.672	2488794.933
Below Bridge St Bridge		
A1-1	5741854.816	2488243.372
A1-2	5741858.83	2488233.787
A1-3	5741868.97	2488212.607
A2-1	5741892.929	2488246.209
A3-1	5741923.953	2488272.549
A3-2	5741927.435	2488266.846
A4-1	5741930.315	2488285.203
A4-2	5741938.92	2488275.142
A5-1	5741929.554	2488291.729
A6-1	5741943.368	2488331.169
A6-2	5741944.784	2488326.847
A6-3	5741947.733	2488320.031
A6-4	5741951.824	2488311.547
A6-5	5741955.449	2488302.951
A6-6	5741959.106	2488294.436
A7-1	5742009.576	2488357.22
A9-1	5742072.151	2488361.102
A9-2	5742072.89	2488359.464
A9-3	5742071.133	2488355.044
A9-4	5742068.193	2488348.906
A9-5	5742062.958	2488338.628
A10-1	5742089.476	2488360.574
A10-2	5742085.999	2488356.175
A10-3	5742083.244	2488348.64

A10-4	5742076.322	2488331.935
A10-5	5742072.665	2488325.154
A11-1	5742104.495	2488348.714
A13-1	5742128.188	2488323.29
A13-2	5742123.593	2488312.014
A13-3	5742120.976	2488301.952
A13-4	5742116.579	2488294.705
A13-5	5742113.186	2488284.612
A14-1	5742190.469	2488284.134
A14-2	5742187.493	2488281.315
A14-3	5742184.997	2488278.727
A14-4	5742182.837	2488275.241
A14-5	5742179.79	2488271.55
A14-6	5742175.506	2488265.575
A14-7	5742171.401	2488262.139
A15-1	5742203.355	2488246.39
A15-2	5742198.35	2488247.862
A15-3	5742190.537	2488237.052
A16-1	5742227.013	2488237.898
A16-2	5742216.094	2488229.313
A16-3	5742207.928	2488221.769
A17-1	5742313.807	2488128.933
A17-2	5742303.467	2488125.471
A18-1	5742345.751	2488066.046
A18-2	5742339.886	2488064.154
A18-3	5742331.077	2488060.484
A19-1	5742362.929	2488009.16
A19-2	5742354.746	2488007.478
A19-3	5742338.351	2488003.338
A20-1	5742383.097	2487982.146
A20-2	5742371.871	2487981.259
A20-3	5742359.716	2487980.84
A20-4	5742350.733	2487979
A21-1	5742479.082	2487900.012
A21-2	5742463.757	2487907.563
A21-3	5742434.346	2487921.128
A21-4	5742368.764	2487946.669
A26-1	5742426.911	2487816.384
A26-2	5742401.706	2487834.767
A26-3	5742373.05	2487854.292
A26-4	5742340.486	2487876.287
A26-5	5742312.267	2487893.981
A26-6	5742284.641	2487910.862
A26-7	5742263.415	2487921.462
A27-1	5742433.579	2487758.893
A27-2	5742426.094	2487762.967
A27-3	5742418.148	2487767.432
A27-4	5742407.979	2487773.953
A28-1	5742414.984	2487762.292
Heathcote Loop		
FT1-1	5738547.794	2486139.864
FT1-2	5738485.606	2486127.031
FT1-3	5738440.683	2486115.09
FT1-4	5738405.095	2486105.655
FT1-5	5738369.151	2486098.142
FT1-6	5738342.321	2486092.267
FT1-7	5738311.582	2486086.824
FT1-8	5738288.259	2486082.244

FT2-1	5738531.34	2486234.614
FT2-2	5738495.819	2486225.622
FT2-3	5738452.401	2486215.5
FT2-4	5738419.078	2486209.023
FT2-5	5738393.125	2486203.783
FT2-6	5738373.679	2486200.673
FT2-7	5738339.347	2486192.757
FT2-8	5738298.361	2486186.609
FT3-1	5738502.656	2486305.086
FT3-2	5738461.311	2486301.987
FT3-3	5738420.277	2486294.981
FT4-1	5738510.427	2486326.417
FT4-2	5738471.047	2486347.696
FT5-1	5738561.92	2486409.301
FT5-2	5738562.313	2486430.811
FT6-1	5738579.3	2486063.382
FT6-2	5738513.502	2486039.073
FT6-3	5738472.295	2486021.871
FT7-1	5738604.079	2486000.913
FT7-2	5738590.074	2485973.402
FT7-3	5738569.967	2485933.961
FT8-1	5738631.347	2485926.222
FT8-2	5738628.003	2485897.4
Charlesworth		
HC1-1	5739176.186	2485970.903
HC1-2	5739175.951	2485955.807
HC1-3	5739173.763	2485937.44
HC1-4	5739177.614	2485911.345
HC1-5	5739175.253	2485891.846
HC1-6	5739178.193	2485869.665
HC1-7	5739182.478	2485851.793
HC1-8	5739185.775	2485830.071
HC2-1	5739209.043	2485972.205
HC2-2	5739208.912	2485951.124
HC2-3	5739208.715	2485932.701
HC2-4	5739210.454	2485917.312
HC2-5	5739212.272	2485891.248
HC2-6	5739211.583	2485872.792
HC2-7	5739211.765	2485849.565
HC2-8	5739209.577	2485835.054
Naughty Boys Island		
I1-1	5743035.113	2487944.128
I1-2	5743051.105	2487995.732
I1-3	5743062.391	2488036.108
I2-1	5743160.155	2487921.529
I2-2	5743171.49	2487995.808
I2-3	5743185.745	2488030.911
I3-1	5743269.192	2487887.185
I3-2	5743280.381	2487922.801
I3-3	5743308.12	2487969.377
I4-1	5743334.455	2487869.448
I4-2	5743346.595	2487901.283
I4-3	5743358.2	2487925.313
I5-1	5743383.847	2487842.266
I5-2	5743387.659	2487865.318
I5-3	5743390.998	2487876.944
I5-4	5743398.084	2487889.581
Avon River (True right bank)		

A29-1	5742480.566	2487752.212
A29-2	5742501.647	2487749.812
A29-3	5742536.436	2487745.75
A29-4	5742590.774	2487741.127
A30-1	5742495.73	2487795.444
A30-2	5742526.608	2487785.252
A30-3	5742552.526	2487777.657
A30-4	5742582.83	2487763.619
A30-5	5742601.363	2487755.557
A30-6	5742612.704	2487751.111
A31-1	5742512.869	2487875.929
A31-2	5742530.695	2487866.663
A31-3	5742549.775	2487854.556
A31-4	5742575.429	2487831.382
A31-5	5742597.905	2487810.897
A31-6	5742617.592	2487793.831
A31-7	5742638.265	2487777.129
A31-8	5742642.232	2487776.243
A32-1	5742751.506	2487867.149
A32-2	5742755.301	2487860.295
A33-1	5742818.925	2487926.086
A33-2	5742824.167	2487920.118
A33-3	5742831.295	2487913.543
A33-4	5742840.308	2487906.988
A34-1	5742868.064	2487973.33
A34-2	5742892.847	2487951.908
A35-1	5742957.917	2488085.724
A35-2	5742961.517	2488081.533
A36-1	5742968.333	2488106.8
A36-2	5742971.999	2488102.26
A36-3	5742977.204	2488096.331
A36-4	5742980.824	2488090.366
A37-1	5743030.537	2488179.763
A37-2	5743031.563	2488165.579
A37-3	5743035.14	2488147.347
A37-4	5743035.212	2488138.06
A37-5	5743036.696	2488127.835
A37-6	5743038.514	2488117.02
A37-7	5743040.042	2488103.592
A38-1	5743080.326	2488162.887
A38-2	5743079.397	2488153.111
A38-3	5743075.35	2488136.987
A38-4	5743071.805	2488125.067
A38-5	5743070.326	2488108.97
A38-6	5743071.307	2488092.85
A39-1	5743088.713	2488161.923
A39-2	5743087.781	2488141.662
A39-3	5743088.914	2488119.719
A39-4	5743085.961	2488095.696
A40-1	5743135.154	2488151.417
A40-2	5743127.577	2488141.58
A40-3	5743125.28	2488129.291
A40-4	5743122.258	2488110.529
A40-5	5743123.513	2488097.945
A40-6	5743126.496	2488080.713
A41-1	5743170.355	2488141.096
A41-2	5743163.816	2488123.175
A41-3	5743159.824	2488098.912

A41-4	5743156.374	2488077.607
A42-1	5743199.901	2488114.289
A42-2	5743195.528	2488102.828
A42-3	5743194.073	2488090.654
A42-4	5743193.116	2488077.293
A42-5	5743191.861	2488071.617
A43-1	5743308.066	2488032.35
A43-2	5743304.518	2488029.049
A44-1	5743398.555	2487947.054
A45-1	5743450.16	2487902.93
A45-2	5743430.322	2487894.59
A46-1	5743469.821	2487897.002
A46-2	5743460.627	2487890.06
A46-3	5743443.745	2487873
A47-1	5743471.33	2487885.215
A47-2	5743457.365	2487863.948
A47-3	5743450.026	2487849.107
A47-4	5743443.68	248737.71
A48-1	5743495.415	2487848.707
A48-2	5743494.56	2487844.552
A49-1	5743532.74	2487837.806
A49-2	5743532.818	2487829.104
A50-1	5743562.3	2487842.522
A50-2	5743563.614	2487833.982
A51-1	5743579.984	2487843.229
A51-2	5743579.77	2487838.815
Avon River (True left bank)		
W1-1	5742423.1	2487485.64
W2-1	5742422.103	2487534.763
W2-2	5742450.049	2487535.611
W2-3	5742475.881	2487537.871
W2-4	5742505.506	2487538.444
W2-5	5742534.978	2487536.173
W3-1	5742536.795	2487495.337
W4-1	5742567.077	2487496.78
W5-1	5742587.449	2487492.589
W5-2	5742585.033	2487508.515
W6-1	5742677.812	2487486.558
W6-2	5742674.364	2487491.796
W6-3	5742674.017	2487504.136
W6-4	5742667.544	2487521.807
W7-1	5742726.166	2487487.346
W7-2	5742708.424	2487508.619
W7-3	5742693.957	2487521.357
W8-1	5742761.422	2487526.461
W8-2	5742756.082	2487531.166
W8-3	5742747.667	2487538.591
W8-4	5742738.202	2487548.151
W8-5	5742726.914	2487558.375
W9-1	5742818.854	2487599.029
W9-2	5742805.048	2487602.06
W9-3	5742789.194	2487605.753
W9-4	5742695.13	2487620.43
W9-5	5742653.099	2487632.722
W10-1	5742853.431	2487665.504
W10-2	5742818.185	2487689.129
W10-3	5742800.554	2487695.949
W10-4	5742767.746	2487710.305

W10-5	5742730.945	2487725.332
W11-1	5742873.807	2487704.035
W11-2	5742860.646	2487704.611
W11-3	5742834.095	2487706.7
W11-4	5742804.699	2487715.02
W11-5	5742789.034	2487721.474
W11-6	5742765.591	2487734.523
W11-7	5742747.144	2487742.764
W12-1	5742880.051	2487725.099
W12-2	5742849.581	2487745.038
W12-3	5742825.097	2487764.957
W12-4	5742796.805	2487786.575
W13-1	5742955.025	2487748.175
W13-2	5742904.205	2487773.314
W13-3	5742827.366	2487806.514
W14-1	5742983.584	2487763.055
W14-2	5742923.359	2487806.755
W14-3	5742888.992	2487832.934
W15-1	5743150.767	2487811.191
W15-2	5743138.731	2487818.726
W15-3	5743113.843	2487833.229
W15-4	5743082.571	2487849.499
W15-5	5743030.799	2487869.769
W15-6	5743025.035	2487884.072
W16-1	5743186.955	2487813.315
W16-2	5743184.406	2487828.474
W16-3	5743184.717	2487839.892
W16-4	5743185.563	2487850.736
W17-1	5743219.327	2487817.086
W17-2	5743217.892	2487823.437
W17-3	5743218.123	2487830.651
W17-4	5743220.455	2487836.144
W17-5	5743222.554	2487846.929
Devils Elbow		
CT11-1	5738608.396	2485764.089
CT11-2	5738623.365	2485776.777
CT11-3	5738632.138	2485785.716
CT11-4	5738654.07	2485801.533
CT11-5	5738671.874	2485815.799
CT12-1	5738632.395	2485759.325
CT12-2	5738668.352	2485788.746
CT12-3	5738711.603	2485828.295
CT12-4	5738740.207	2485861.145
CT13-1	5738645.68	2485734.073
CT13-2	5738667.869	2485752.4
CT13-3	5738693.346	2485774.426
CT13-4	5738733.905	2485817.786
CT14-1	5738674.468	2485707.288
CT14-2	5738693.658	2485743.7
CT14-3	5738712.651	2485774.038